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Second International Handbook of Science Education

Volume 1

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Second International Handbook of Science Education

Part One

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Preface

Because the field of science education had been developing and flourishing for over half a century, it was timely and fitting that the first *International Handbook of Science Education* was assembled in 1988 to synthesise and reconceptualise past research and theorising in science education, provide practical implications for improving science education, and suggest desirable ways to advance the field in the future.

This *Second International Handbook of Science Education* demonstrates just how much and how rapidly the field has evolved, expanded and diversified over the last decade or so. In providing a detailed and up-to-date overview of advanced international scholarship in science education, this two-volume, 96-chapter, 1,400+–page work is the largest and most comprehensive corpus of knowledge and resource ever produced in science education for use by researchers, teacher educators, policymakers, advisers, teachers and graduate students.

In structuring this *Handbook*, we divided the field of science education into the following 11 significant areas:
Sociocultural Perspectives and Urban Education

- Learning and Conceptual Change
- Teacher Education and Professional Development
- Equity and Social Justice
- Assessment Evaluation
- Curriculum and Reform
- Argumentation and Nature of Science
- Out-of-School Learning
- Learning Environments
- Literacy and Language
- Research Methods.

In designating this *Handbook* as ‘international’, we wanted to have a book that would have significance to readers from many countries. Consequently, authors have included research from a variety of countries and broad geographic coverage was considered when selecting authors. Altogether 172 authors from 20 countries were involved in producing this *Handbook*.

We especially would like to thank our chapter authors for being part of this enormous publishing enterprise and for being patient with us when we were unable to keep all the balls in the air at once. Also we are grateful to everyone at Springer and Curtin University who helped to bring this major task successfully to fruition.

Editors

Barry J. Fraser, Kenneth G. Tobin,
and Campbell J. McRobbie

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Part I
Sociocultural Perspectives and Urban Education

Chapter 1
Sociocultural Perspectives on Science Education

Kenneth Tobin

After 36 years of studying the teaching and learning of science, it is clear to me that there are many ways to teach in order to produce success and just as many ways to teach to produce failure. Being an effective science teacher entails much more than changing one or two variables and maintaining high expectations for the achievement of youth. Instead, effective teaching is complex, necessitating that teachers enact successful chains of interactions, not just for one person, or even one person at a time, but for a social network, producing and sustaining learning environments built upon fluent transactions that facilitate collective and individual outcomes. Teaching science is collective, and it is important that all participants, teachers and students, have a sense of the game that affords forms of participation that are timely, appropriate, and anticipatory. Central to productive learning environments are individuals who act not only for themselves, but also for the collective; that is, they enact practices not only intended to promote their own achievement but also to expand the agency and learning of others. Accordingly, each learning practice also becomes a teaching practice and teaching and learning are regarded as dialectical constituents of a learning environment. The essences of a dialectical relationship are irreducibility and copresence, each entity presupposing the existence of the other. I employ dialectical theory to avoid the creation of binaries and the use of either/or logic and I depict dialectical relationships using the following convention, teaching | learning, in which the vertical stroke is indicative of a dialectical relationship between the adjacent constructs.

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Illuminating Science Education with Sociocultural Theory

Making Sense of What Happens in Science Classes

I adopt an ontological stance that theory illuminates experience, affording participants making sense of their social lives. This stance is salient because in the everyday unfolding of events participants do what they do without epistemological engagement and it is only when there is a breach in the flow of interactions, when the unexpected occurs, that actors take stock of what has happened and reflect on action. On such occasions those actions deemed to have salience become epistemic objects and can be examined in terms of a theoretical standpoint. Because so much of what happens in social life happens without conscious awareness, reflexivity is important for actors, such as science teachers and their students, so that they can identify aspects of their practices and their supporting rationale, changing them as desirable to benefit the collective. Thinking back on what happened during a science lesson with the purpose of identifying desirable changes necessitates evaluations being made about what is and is not working for the benefit of the teachers and students. Reflecting on practice is a recursive activity in which a theoretical standpoint illuminates experience and affords goals such as identifying roles and associated practices that can be changed for the purpose of improving learning environments. The standpoint used to identify salient roles and practices is also an object for potential change. Since the use of different theoretical lenses can lead to different events being considered salient, it is important for teachers and learners to become aware of and understand the theoretical standpoints they use to make sense of learning environments. Also, participants in a field should be willing to understand others' standpoints and consider their viability. Hence, when teachers and students consider changes to learning environments, it is not just roles and practices that are objects for change, but also the participants' standpoints, which give meaning to questions such as what happened, what should happen, and what is of value?

My Framework

I examine science education through the lenses of social and cultural theory, adopting a standpoint that considers science as cultural enactment. When science is done (i.e., enacted), like other forms of culture it can be considered as a dialectical relationship between production and creation. I use dialectically related constructs for enactment involving agency (i.e., production) and passivity (i.e., creation), constituents of a whole that do not exist independently. Cultural production involves agency, is goal oriented and intentional, and occurs when actors consciously appropriate structures (e.g., a student responds to a teacher question about an oscillating pendulum gradually losing its energy). Simultaneously, cultural creation occurs passively and may be unrelated to goals even though an actor is aware of culture being created over which she/he does not have complete control (e.g., creation of negatively valenced emotions while balancing equations). Accordingly, cultural enactment involves agency and passivity, which are dialectically related to one another and to the extant structures.

Most models for learning science have emphasized agency and focused on the learning of individuals (Roth 2007). From a sociocultural perspective, however, individuals are dialectically related to collectives, and agency cannot exist independently of structures or passivity. Hence, agency is both individual and collective and is reliant on a dynamic structural flux that characterizes social fields. Roth and Calabrese Barton (2004) discussed scientific literacy as collective and provided compelling accounts of the ways in which collective goals (hereafter motives) are accomplished when individuals agree on and enact a division of labor that includes coordinated action toward the agreed motives. That is, the goals of an individual are dialectically related to the collective's motives. For most educators, thinking of the outcomes of science in collective as well as individual terms is a novel experience that points to a need for different forms of activity, such as cogenerative dialogue (hereafter cogen), which is considered later in this chapter as a means of establishing productive dialogues between teachers and students in which all participants learn from one another. As Michel Juffé (2003) notes, passivity can be thought of as receptivity to learn from others. Being-in-with others is a sufficient condition for learning passively as science is enacted in a field (including a science classroom or informal learning institution such as a museum). Hence, science learning occurs even when participants do not have the goal of learning science and when they are unaware that they have learned. Reflexive practices at a later time can reveal what has been learned (i.e., awareness and potential worth of what has been learned).

Many scholars totally misunderstand the nature of passivity, thinking of it in behavioral terms. That is, they think of passivity as not being overtly involved in an activity. On the contrary, a person who is agentic simultaneously learns passively. Based on our research in urban schools, the factors that seem most salient to receptivity to learn are: being-in-with others doing science (i.e., physical proximity); solidarity with others; cosmopolitanism that unites subgroups based on differences within and between social categories; possessing a science-related identity; having positive emotions toward science and doing science; recent success in science; and willingness to invest the emotional energy needed to initiate and sustain participation. When the emotional energy of a field is positively valenced all participants have opportunities to create a shared mood that is positively valenced, contributing to receptivity to learn and possibly expanding agency as well.

Structures as Affordances for Enactment

I use social field in much the same way a physicist might use magnetic, electric, and gravitational fields. A social field is a site for cultural enactment and is constituted by structures, which are resources that afford cultural production and creation. Because they are unbounded, fields are uncontained by space and time, which are considered as structures. Examples of other structures include individuals and their characteristics, equipment and materials, goals and schemas, and social categories such as age, gender, race, ethnicity, religion, and class. Participants' practices, which are simultaneously structured and structuring, are an integral part of a dynamic structural flux that characterizes a field and affords enactment through agency and passivity. Because the structural flux is indeterminate, agency is expanded by the possibilities afforded by the unfolding enactments of social life. Of course, to the extent that similar structures have been encountered previously, aspects of the structural flux can be anticipated and appropriate knowledge can come to hand just as it is needed (i.e., structural resonance or entrainment occurs). In such circumstances cultural fluency is afforded and it is only when unexpected structures arise that fluency is breached (e.g., when anticipated structures are not available in time and/or when unanticipated structures emerge). Accordingly, participants in a field might find it beneficial to participate in reflexive activities (e.g., cogen) in which they take stock of what is happening – identify what is working satisfactorily, what changes are desirable, what is possible, and what has been accomplished.

When it comes to applying the idea of a field, the decision of where to focus depends on the purposes of a study and what is usefully regarded as a field. For example, choices to examine science education within a school, or a class within a school, are convenient but arbitrary and are analogous to using a zoom lens in microscopy. If a researcher's gaze focuses on a science class, then field can be a useful theoretical entity to illuminate what is happening in the class. If the gaze moves to the participation and learning of Black females, for example, then the field can be considered in terms of those participants and their activity. The scope of a social field can vary from the global (e.g., including macrostructures such as neoliberalism) to the molecular level involved in neural processing and all magnitudes in between. Similarly, time can vary from exceptionally long to extremely short, reflecting the purposes of a study and the tools used to support inquiry. From an analytical standpoint, it is important to remember that structures interpenetrate all fields of an individual's lifeworld, thereby mediating activity (i.e., the enactment of culture). Because of the agency | passivity dialectic, what happens in a field is afforded by structures, not determined by them (i.e., individuals always are agentic while being passive with respect to a dynamic flux of structures).

When participants enact culture in a field, there is a tendency to reproduce culture that is similar to what has been produced in the field historically. For this reason, an investigation might productively examine cultural enactment as a function of time, identifying patterns over long and short periods of time. Some structures in the field of science education are relatively stable. For example, despite an exponential increase in the production of science knowledge, the K–12 curriculum has been little changed in a half a century. Also, looking at patterns over a shorter time span, the science subject matter taught varied from day to day. Similarly, teacher and student roles and practices vary when viewed from minute to minute, however, when viewed from week to week, or month to month, discernible patterns are similar to those I described in the 1980s (e.g., Tobin 1987).

In fields in which science education is enacted, it is important to explore the implications of individual | collective relationships and examine the roles of individuals in relation to their goals and motives. A division of labor can be considered with the motive of expanding collective agency – that is, individuals acting for the benefit of others. In order to do this, it is important to embrace a value of supporting others' agency and assuming co-responsibility for facilitating others' goals. If this occurs, a likely outcome would be solidarity; based on a heightened sense of belonging to a collective and the desirability of creating coalitions that bring together subgroups that might be defined by social categories, such as race, gender, class, and native language. A form of solidarity that transcends subgroups is cosmopolitanism (e.g., Appiah 2006), regarded as a vital outcome of science education as it is enacted in diverse social settings (i.e., in fields in which there are numerous salient social categories associated with participants such as native language, gender, and ethnicity).

Solidarity and Science Education

Solidarity is a form of symbolic capital, a sense of belonging to a social category, such as youth having an interest in science. For example, in a high school science class in the Bronx, a central feature of students' identity might be defined in terms of the poles of a binary – speakers and nonspeakers of Spanish. The symbol of speaking or not speaking Spanish can thus become an identity marker and a form of capital used in creating social bonds and networks. That is, speaking Spanish can become a social category that affords solidarity and the co-emergence of two groups. This might manifest in participants' preferences for selecting those with whom they prefer to work and be seated. Similarly, social categories such as gender, race, and class can act alone or in combination to afford solidarity among clusters of participants within a field. In such circumstances, cosmopolitanism, the creation of solidarity across clusters, is a desirable outcome.

Scholars such as Jonathan Turner (2002) and Randall Collins (2004) have undertaken work in the sociology of emotions that is central to the creation of solidarity and cosmopolitanism in science education.

Cosmopolitanism

Turner researched the evolution of human emotions in terms of theory that includes primary, secondary, and higher-order emotions. He posited four primary emotions, three negatively valenced (fear, anger, sadness) and one positively valenced (happiness).

As social life is enacted, emotions are produced continuously, contributing to a valenced emotional climate. Turner referred to this using the analogy of emotional energy (EE). As a structure, EE serves the production and creation of culture. Usually I consider EE as positive, neutral, and negative. Empirically, it makes sense to look for spikes in the EE spectrum, that is, when emotions are strongly positive and negative, and the culture associated with them.

The school in which our research is situated in New York City draws on youth from a densely populated neighborhood. Through immigration and recent ancestry, these youth are associated with several ethnic groups including Puerto Rican, Dominican Republic, African-American, and Caribbean. In this instance, ethnicity can be a kernel for producing solidarity, as is Spanish, the native language most students speak. Within most classes it is not uncommon to find youth sitting in ethnic groups or native language groups. Social categories such as these can serve as bases for spending time together and being with others who are similar. That is, categories of difference can draw similar others into proximate space–time, allowing them to identify with one another and experience feelings of solidarity, based on their affiliation with a group.

Groups form within science classes and youth tend to identify with those groups. Since there are multiple groups, students can create, sustain, and reinforce multiple identities in a science class – identities that have little or nothing to do with science. Of course, this can be an advantage, because the identities that develop in conjunction with factors such as native language, ethnicity, and gender can be tied to science. However, this may take a conscious effort (i.e., agency), on the part of all participants, and adherence to science-related motives. The creation of a science identity that transcends multiple identities associated with other social categories requires a form of solidarity that brings together subgroups that are akin to diasporas (Hall 1990), or homes away from home. Kwami Appiah (2006) refers to this superordinate form of solidarity as cosmopolitanism, a topic that was studied by the ancient Greeks and consistently from then on (e.g., Parsons et al. 2007). The key idea in science education is to consider cosmopolitanism as a goal when other criteria are continuously reinforcing identities associated with difference, such as those I have discussed already. Jacques Derrida wrote an essay on the creation of cities of refuge; cities where refugees were welcome to come, not just to visit, but also to reside (Derrida 2006). A defining criterion for these cities was that each citizen needed to embrace the goal of affording community life while retaining the right to be different. Differences were seen as resources to allow the city to flourish. Therefore, the challenge was to find divisions of labor in order to take advantage of what different citizens within the city could do and accomplish, and ensure there was an alignment of what different collections of individuals did and motives for the city. The glue that held together different constellations of difference was a value for the right to be different and a sense that difference was a resource that could benefit the collective. Establishing cosmopolitanism in science education might fruitfully be considered analogously to cities of refuge.

In a science class, cosmopolitanism is not an end state, but is constantly being built as interactions unfold during science classes. The accomplishment of cosmopolitanism necessitates awareness and a continuous investment of EE. A tendency to fragment is likely to always be present and it is important that students are reflexive about cosmopolitanism and make serious efforts to nurture it. One of the most important outcomes deriving from cosmopolitanism, is the production | creation of science-related identities. If a science class can establish and maintain science-related identities, then participants can work together to produce higher levels of achievement and ultimately forms of success that are negotiable in the community at large. However, the challenges are many in urban schools such as those in New York City. It is not only students that differ in terms of social categories such as those I have mentioned but also teachers. For example, although Reynaldo Llena, a Filipino chemistry teacher, speaks Spanish, it is not his native language. Ethnicity and native language are social categories with the potential to set such teachers apart from their students (Tobin and Llena 2010). Accordingly, Llena embarked on a multiyear project in which he used cogen as a means of producing solidarity and cosmopolitanism, not just as outcomes but also as processes that needed constant attention. In the next section I address the nature and application of cogen as activities and methodologies, not just in research, but also for learning to teach, curriculum development and enactment, and learning to learn.

Cogenerative Dialogue

For the past 6 years we have been using cogen in ongoing research in New York City. This research builds on an earlier program that is ongoing in Philadelphia. The production of cosmopolitanism has been an important focus, not just as an outcome but also as a process that was closely linked to other valued outcomes such as increasing achievement on the State Regents examinations. One of the sites for this research was New York High where Llena, the chemistry teacher referred to above, was a central figure as a teacher researcher (e.g., Tobin and Llena 2010).

Cogen involves more than discussions among representatives of the key stakeholder groups in a school, science department, or class. Representation is an important criterion and so too is participation in an ongoing dialogue in which attentive listening is a valued component. The number of participants should afford ample opportunities for speaking, listening, and being reflexive about what has been happening. If speaking is to structure everybody's participation, then it needs to be external to the individual; that is, it cannot be inner speech only. This criterion often limits the number of participants in cogen. Our experience is that somewhere in the vicinity of five to nine participants is ideal, allowing for differences to be represented in a variety of social categories and, in approximately 45 min, ensuring that all participants have turns at talk and opportunities to listen and learn from others as they speak.

When we first established cogen, we focused on selecting participants who were different from one another. We wanted to obtain diverse perspectives on what was happening in a shared classroom experience and to do our best to learn from those perspectives. We were not interested in finding out what happened on the average; we wanted to know how individuals experienced the class, what was common, and what was idiosyncratic. Initially, we started with two to three students and any teachers who had been teaching in the class. Since we planned cogen in conjunction with coteaching, it was frequently the case that cogen also included two to three coteachers who, with the students, participated in a dialogue over shared experiences.

The dialogue focused on improving learning environments and facilitating success for all participants. It soon became apparent that there was little point in participants blaming one another for identified problems. If something was not working there was shared responsibility for making things work in ways the group endorsed. Hence, there was an initial priority to accept shared responsibility to enact in the classroom what was agreed to in cogen. Not surprisingly, this led to students taking a more active role in teaching science. If participants accepted responsibility for enacting what they agreed to, it seemed reasonable that they would get up from their seats during class to ensure that their peers' actions aligned with the motives of the class, use the chalkboard to clarify aspects of the science content that needed to be elaborated or clarified, and generally circulate to ensure that any peer in need of assistance could obtain it. Accordingly, one of the first changes we noticed in classes that incorporated cogen was that students got involved as peer teachers, that is, they became coteachers. In so doing changes were noticed in the ways in which spaces and other natural resources were utilized by teachers and students. For example, students often moved freely about the classroom and worked at the chalkboard.

Speaking for Others

In cogen, one of the rules is to share the turns at talk. All participants need to agree to a rule that the distribution of talk is equitable. Our research suggests that participants speak for approximately the same amount of time and have approximately the same number of turns at talk (e.g., Tobin 2006). In fact if this is not the case, there is shared responsibility to talk in ways that encourage those who are silent to speak. Accordingly, students who often said very little in class began to speak more; other participants listened to them, and what they said clearly made a difference to negotiated outcomes. Participants in cogen realized that they could have a voice and what they had to say could make a difference. Participants learned to talk in ways that would produce agreed-to outcomes and, importantly, talk in ways that would benefit others in cogen (e.g., expand their agency). Speakers were talking for the other. That is, when a person speaks, he or she contributes in ways that expand the agency of other participants, not only speaking for the purposes of the talker, but also to benefit others in cogen. Speaking for the other is a desired outcome that is accomplished more often than not in cogen.

Maintaining Focus

Establishing and maintaining shared focus also was a rule of cogen. We expected participants to listen attentively to what was said and only to speak in relation to what was said previously. Speakers were not encouraged to change the topic unless there was agreement that a change of topic was to occur. In this way the dialogue stayed focused on the matter at hand until a resolution was reached (i.e., a cogenerated outcome). All participants were encouraged to ask what have we cogenerated? By keeping this issue on the table, the talk tended to be focused and synchrony occurred in terms of what was said and what happened next. Widespread synchrony within cogen, referred to as entrainment, is a precursor to solidarity, a shared mood, and frequently collective effervescence such as laughter, clapping, and overlapping speech (Collins 2004). We began to see examples of participants becoming like the other, presumably afforded by mutual focus established and maintained by the rule structure of cogen. By retaining focus, synchrony was a common phenomenon, producing entrainment, which often comprised sets of similar actions distributed broadly across a social network.

Radical Listening

Productive cogen necessitated careful listening of all participants. One person spoke at a time, and the others listened attentively. However, there is more to it than just listening attentively. Radical listening requires participants to understand what is being said, consider the associated standpoint, and understand the implications of what is being said for practices in the classroom (Tobin 2009). (Joe Kincheloe introduced this idea to me in an unpublished manuscript.) Radical listening requires each participant to understand the standpoint of others, figure out how to adopt those standpoints, consider implications of adopting them, and in ways that are reminiscent of thought experiment, consider implications of adopting practices that are consistent with others' standpoints. Rather than immediately searching for the shortcomings of a particular standpoint, radical listening necessitates the identification of its inherent strengths. The listener is required to understand and apply someone else's standpoint and carefully consider plausible outcomes and their viability for this collective – in this case a science class.

Expanding Participants' Roles

In order to reap the potential of cogen it is necessary for participants to produce and create new culture that is then potentially available to be enacted in other fields of the participants' lifeworlds, including the science classroom. Creating new culture that affords success is an outcome of cogen that opens up possibilities that have profound implications for the way that education is conducted in schools around the world.

A goal of cogen is the production of new roles focused on improving the quality of learning environments. There was evidence that the new culture produced in cogen was subsequently enacted in the science class (e.g., Tobin and Llena 2010). That is, cogen was a seedbed for the creation and production of new culture that could be used subsequently to improve the quality of learning environments. Participants were encouraged to bring artifacts from the class to cogen so that they could be used to focus the unfolding conversation. Accordingly, students and teachers brought work from the class, digital images of inscriptions from the chalkboard, evidence of students' participation in science tasks and off-task conduct, textbook pages, and other resources used in the class as aids to learning. A significant moment in the evolution of cogen was the use of digital video to capture what was happening in the class. Students and teachers found it useful to digitally record the lesson and then at a later time analyze what was happening by replaying and editing to capture vignettes deemed to have salience. Subsequently, these vignettes were brought to cogen and focused participants' interactions. Microanalysis was used to examine the quality of interactions and especially the way individuals spoke to one another, reacted to what was said, and acted for the other. Having video as a point of reference, has greatly enhanced the quality of dialogue and moved it toward evidence-based arguments, conversations, and resolutions.

Teachers and students in cogen became researchers of their own practices and shared the goals of finding out what was happening and figuring out why what happened did happen. There was a need to adopt different standpoints to make sense of their experiences and before long participants were willing to learn and apply new theories in a quest for understanding what was happening in their classroom. Accordingly, participants became interested in issues such as whether or not mutual focus occurred and was sustained, whether there was synchrony, entrainment, shared mood, collective effervescence, and solidarity.

Curriculum Change

Many good ideas for changing the enacted curriculum arose from cogen. For example, in one cogen students felt that the class lacked variety and interest. They proposed that the teacher use a game format during the next class and she willingly agreed to plan a lesson around a quiz show called *Jeopardy*. The teacher enacted this plan in a review lesson on genetics, and the students enjoyed the format and agreed that it could be used at least once a week to increase their levels of interest in what was happening in the class. This is one example of how a cogenerated idea led to changes in the enacted curriculum. Another example, also in genetics, involved students using video and their video editing skills to produce Podcasts that could teach peers in that class some aspect of genetics. This too was implemented and students learned by producing teaching resources for peers and also by using the resources that others produced. The students in cogen thereby became curriculum developers; using skills they developed for research to produce curriculum resources used to improve learning environments. A final example involved the use of hip-hop. The youth involved in cogen had an avid interest in hip-hop and many of them were interested in writing lyrics that incorporated the science they were learning. Other students were good at creating a beat to coordinate with the lyrics and worked collaboratively to produce a rap that could then be performed in the class as an example of what others could do in their quest to learn science. In this way rap was incorporated into many science lessons with some students working together in small groups to produce lyrics while others prepared beats to synchronize with the lyrics, thereby producing a rap that everybody could learn and perform.

Llena had an idea that youth participants in cogen could serve as mentors for others in their class and in other sections of the course he was teaching (in this case living environment). He developed a buddy system, in which each youth participant in cogen identified at least one buddy for whom she/he would become teachers and "buddies." The youth would ensure their buddies were ready for school, did their homework, arrived on time, came to class, and stayed engaged during each lesson. If a buddy experienced difficulties in class, the youth mentor would teach her/him about the subject matter of the lesson. Llena adjusted the assessment system so that those who accepted a mentoring role would earn credit if their buddies increased their achievement. The more the buddy increased her/his achievement the higher the grade of the mentor. The buddy system was a great success and it was not uncommon to see participants from cogen actively teaching their buddies during class time.

Cross-Field Production and Creation of Culture

Students were encouraged, developed confidence, and were aware that adults could and would listen to them and act on what they had to say. It was not surprising, therefore, that once students discovered they had a voice that could make a positive difference they spoke up in other fields, in and out of school. For example, youth involved in cogen not only cotaught but they also approached school administrators to make other changes to school structures (Bayne 2009). These included suggestions that other students should use cogen too, not only in science, but also in their other subjects. In one school this resulted in cogen being used in the middle grades so that students would develop more school spirit, and school-related identities. This suggestion was made by one of the participants from the high school, who had done cogen for 3 years and realized widespread benefits. Many of the youth who participated in cogen became involved in student government, several becoming chair of the school council.

At New York High, a group that had experienced cogen for 4 years suggested a series of turnkey activities involving grade 12 students teaching students from grade 9, and their teachers, how to enact cogen. Grade 12 students told students from other year groups about the benefits of cogen and encouraged their teachers to use them (Tobin and Llena 2010). Some of the teachers were reticent to do this and many students doubted that the teachers would listen to them. Clearly there was a lack of trust. However, the youth persevered and several years later there is evidence that even the most skeptical teachers adopted and successfully used cogen to improve the quality of learning. Evidence of success includes increased performance of students on statewide, standardized tests. Although we did not actively pursue this goal as a research group, performance on high-stakes tests is a gold standard in New York City, and it was a plus that cogen produced higher achievement scores on highly valued assessments. It is also noteworthy that students who often dropped out of high school participated in cogen, achieved success in their high school studies, and made the decision to go on to university. Hence, participation in cogen was an activity that produced success, changed identities, and produced forms of practice that transformed and expanded the possibilities of urban youth.

Prosody and Emotions

Participants in cogen became aware of the centrality of emotions in all interactions and events that occurred in the science class. As our research expanded and we became interested in the emotional content of talk, students and teachers also were interested in prosody and students from one class drew attention to the anger their teacher displayed as he taught. They drew his attention to features of his speech they interpreted as anger. The teacher assured them he was not angry, that he was interested in their learning, and would attend to what they had told him about the way he spoke. Apparently, differences in ethnicity between the students and the teacher led to misunderstandings about the emotional content of interactions and these misunderstandings mediated the creation of emotions, in this case creating negative emotions such as frustration and anger on the part of the students who perceived the teacher as angry with them for no good reason. Building trust, respect, and tolerance were outcomes of cogen – not just for students, but also for the teacher. Hence, the production of success in cogen created social bonds associated with affection between participants, increasing solidarity with the potential to translate to cosmopolitanism in the science class.

Emotions are a central part of action; that is, when we act our emotions are put on display in how we move and use our bodies, including gestures, facial expressions, head movements, and speech. For example, when we are excited, those who are in sync with us experience our excitement as we interact with them. High-energy teachers, for example, communicate their emotions to a class in the ways they coordinate their bodily actions and characteristics of their speech. Similarly, if a person is angry, others having a history of interacting with that person can "read" the anger, because it is visible in the person's actions. Humans who have intense and prolonged experiences with others can quickly pick up their emotions based on just a small number of encounters – "Oh, she is in a bad mood, I should avoid her for a while!" Or, "he is angry, I should let him sort this out before I raise these issues with him." These are just two examples of the kinds of thoughts I have when I approach people that I know and quickly size up their emotions prior to commencing my interactions with them. In our research we have begun to zero in on ways to measure the emotional content of actions.

During a routine set of classroom interactions, prosody analysis usually reveals numerous alignments in terms of pacing, pitch, and intensity. Synchrony also was found in terms of intonation, with successive speakers inflecting utterances as evidence of a shared mood. Research on these alignments and synchronies must take account of natural variations in the voices of adults and children, males and females, for example. We have seen examples of science teachers intentionally producing misalignments in an endeavor to change the emotional climate in the classroom. For example, high-energy teaching might involve exaggerated body movements, including verve, and prosodic features that are loud, unusually contoured in regard to frequency and intonation, and energy laden (i.e., high intensity in the higher-order formants). If participants become like the other by being with the other then students in the class of a high-energy teacher might begin to interact in high-energy ways simply by being in the classroom with the teacher. Of course symmetry can be anticipated and a loud and noisy class creates a structural milieu to afford loud and noisy teaching. My point is that misalignments or asynchronies can be intentional, the purpose being to alter the emotional climate and create a shared mood of a particular nature.

Misalignments can also cause trouble. We have experienced classroom climates that have spiraled out of control as successive speakers infused high-energy emotions into their speech. We called this heating up the climate. We noticed in the same classes, that when students spoke after one of their peers had made an angry utterance, their speech contained less emotional energy than that of the angry speaker (Roth and Tobin 2009). That is, they spoke "under" the previous speaker. Speaking over or speaking under is equivalent to heating up or cooling down the climate, respectively. When participants know the culture of the other, it seems they can anticipate what is to come based on what they have experienced so far, and they can act accordingly in ways that do not produce trouble. That is, they act appropriately to reproduce cultural fluency, thereby affording outcomes that align with the motives.

Potential for Change

More than a decade of research in science education employing a sociocultural framework has illuminated the folly of policies grounded in the macrostructures of neoliberalism, meritocracy, and accountability systems that focus on individuals' efforts and accomplishments. At the very least, our project suggests that it is time to step back and critique the assumptions and practices that have produced and reproduced what are euphemistically referred to as failing schools. Predictably, schools that fail are associated with lower levels of per capita student funding, race, ethnicity, and English proficiency. Use of a sociocultural framework provides windows into the practice of science achievement that afford explanations for the gaps we have experienced in science education and for the myriad tests of international comparison that show the USA lagging behind its economic competitors. Furthermore, the sociocultural framework illuminates an array of alternatives that promise to redress the ongoing and pervasive inequities that characterize science education.

The first tip I can remember receiving about being a good teacher resonates in my mind: "As they walk in the door on the first day, identify the biggest male student and politely request that he pick up a piece of paper from the floor. Show the class that you are in control." The advice made sense because it aligned with my experiences as a schoolboy – my best teachers all had quiet and busy classes in which students were highly involved. I accepted the viability of the assertion that environments like this were established and maintained by teachers exercising control over their students – they kept them quiet and productively engaged. School leaders and other judges of good teaching even maintained that they could assess good teaching by simply listening at a window or from behind a closed door. The ultimate test was that the noise level would not increase when the teacher left the room.

Sociocultural perspectives (e.g., associated with social class and race) highlight the salience for teachers and students of collaborating to produce and sustain productive learning environments. From this standpoint it makes no sense to regard teaching as the responsibility of just one person – teaching is radically collective. Accordingly, there are many implications across myriad domains of education policy and practice. Also, in teacher education and credentialing there are crucial implications that must be addressed. What is teacher knowledge? To what extent does teacher knowledge learned in one field transfer to other fields? Are there appropriate ways to assess the quality of teaching and make choices about which teachers are optimal for particular schools and classes? When it comes to teaching science, what is the appropriate balance between knowledge of science and knowledge of teaching science? Who should make the decisions about which teachers to hire and which teachers to assign to particular classes? And when it comes to doing research on teaching, who are the most appropriate researchers and how will they collaborate to produce viable outcomes? Also, to what extent is the purpose of research to produce new theory and to what extent is it to produce improved practices and policies? These are just a few of the many questions that warrant our attention; questions that produce answers with implications that may not have been considered from the different theoretical standpoints that have been traditionally adopted. Rather than addressing issues such as teacher education, research in classrooms, science curriculum development and enactment, and formulating policies to afford urban science education, I simply note here that it is past time for educational researchers to be reflexive about what they do and where they are going, using sociocultural lenses to augment those that have been used traditionally. It must be clear to all that the tried and tested methods have failed, and will continue to do so for as long as scholars and policy makers consider individuals in isolation from associated collectives and insist on accountability models that embrace individualism and meritocracy. It is no longer a question of trying to improve what we do, it is time to question what we do and seek alternatives, including the use of different rationale for identifying priorities and selecting among alternative pathways. The moment for change is now.

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Chapter 2
Understanding Engagement in Science Education: The Psychological and the Social

Stacy Olitsky and Catherine Milne

It is a prevalent understanding among teachers, curriculum writers and education researchers that students need to be engaged in order to learn science. Empirical studies in education indicate the importance of student engagement for effective teaching and learning (e.g. Ainley et al. 2002). Many teacher education programmes advocate a focus on engagement when they promote pedagogical strategies based on constructivist views of education. Such programmes encourage teachers to provide opportunities for students to build their own meanings in science through direct experience, rather than the more traditional transmission models of teaching (e.g. Duckworth 1987). Pedagogy based on a constructivist approach implies student engagement in that the students need to be active, making sense of their world through integrating their new experiences with their prior experiences, beliefs and knowledge (Driver et al. 1994). One example of an approach to science teaching developed in accordance with constructivist thought is the 5E instructional model, which consists of the following phases: Engagement, Exploration, Explanation, Elaboration and Evaluation (Bybee 1997). According to this model, the first phase, student engagement, can be fulfilled through some type of short experience that is designed to access prior knowledge and stimulate curiosity. Similarly, in many teacher education programmes, teachers are encouraged to engage students by designing lessons with some kind of a 'hook' that is supposed to gain students' attention and pull them into the subject matter.

Constructivist perspectives, both personal and social, primarily focus on the cognitive aspects of engagement, in that the emphasis is on cognitive tasks such as questioning prior beliefs or building on prior knowledge. However, in order to

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implement pedagogical strategies based on constructivism, engagement on an emotional level is crucial. For example, students need to be excited by the 'hook', or have positive emotional tone associated with the process of questioning their ideas in order for such strategies to be effective. Paul Pintrich, Ronald Marx and Robert Boyle (1993) were critical of models for student learning that focused only on 'cold' cognition, ignoring the role of student engagement in classroom activities. Further, empirical research has also affirmed the importance of engaging students on an emotional level (Alsop and Watts 2003). Mike Watts and Steve Alsop (1997) argued that theories, such as conceptual change, need to take into account the emotions behind actions if learning in science is the final goal of developing such theories. If we assume an active learner, an agent, then it makes sense to acknowledge the role of emotions in engagement. However, in order to do that, we need to develop a richer understanding of the nature and role of engagement in classroom contexts.

Such clarification is important, because the everyday use of the term 'engagement' among teachers emphasises the slipperiness of this idea as it currently emerges in discussions about pedagogy. For some teachers, engagement is an individual construct evidenced when they talk of a student who is 'disengaged'. This places an attribute, and perhaps responsibility, on that student. Sometimes teachers describe how they did not sufficiently 'engage the students', which then places the focus and the responsibility on the individual teacher. For others, engagement is collective, with teachers describing how students and teacher become so caught up in a lesson that they are surprised when the end of class is signalled.

In this chapter, we examine new research in which engagement is posited as emerging from collectively generated emotions, which then has implications for both cognition and behaviour. This social and emotional view of engagement does not mean that individuals' actions are thought to be irrelevant. Rather, attention to the collective aspects of engagement means that an individual's actions are not understood as a product of some kind of inclination or personality trait (e.g. this child is disengaged or shy). Instead, we follow the sociologist Randall Collins in viewing individuals as products of social situations, and argue for a dialectical relationship between the social and the individual.

We develop, illustrate and support our view of engagement by describing outcomes of our research that illustrate how collectively generated emotions led to changes in both behaviour and cognition within two science classrooms in Philadelphia. Similar findings about the results of engagement from two very different schools support the primacy of the social and emotional aspects of engagement in influencing other dimensions of engagement, and have implications for paths that teachers can take in order to implement positive classroom changes.

Conceptions of Engagement

Much of the research that informs current understanding of engagement in science education comes from behavioural or cognitive studies. Jennifer Fredricks, Phyllis Blumenfeld and Alison Paris (2004) proposed a multifaceted model that consisted of behavioural, emotional and cognitive engagement. They identified *behavioural engagement* as engagement associated with a range of actions from students' classroom behaviours, including on-task behaviour and participation in extracurricular activities. *Emotional engagement* is associated with students' attitudes, interests and values as identified in a student's reactions to peers, teachers, the curriculum content and school. *Cognitive engagement* is associated with motivational and self-regulated learning. Cognitive engagement could be identified from students' willingness to 'exert the effort' that was required to understand 'complex ideas and master difficult skills' (Fredricks et al. 2004, p. 60). The authors argued for the importance of thinking of engagement as a mega-construct that was composed of interrelated aspects of behaviour, emotion and cognition and for understanding engagement in each construct as existing on a continuum. They acknowledged the limitations of single variables for characterising the responses of children to specific tasks or activities and argued for the fusion of behaviour, emotion and cognition under the concept of engagement. Further, they identified engagement as a malleable construct that was open to changes in the context. While their review was helpful because it synthesised extant research on engagement, we do not think that the model of three separate continua is the most accurate perspective, because it begs the question of the complex relationship *between* cognition, emotion and behaviour. However, as we argue later in the chapter, social theory provides strategies for understanding this relationship.

If we look at research on engagement conducted over the past 20 years, we find that many studies adopt a focus on individual engagement. For example, in science education, consistent with the prevailing learning theories, early studies of engagement focused on individual students and measures such as 'time on task' as indicators of engagement (e.g. Tobin and Capie 1982). Even now, while researchers investigating engagement might acknowledge the importance of the social, they still rely on research methods such as interviews and surveys that seek individual measures of engagement. For example, acknowledging the limitations of a purely behaviourist approach to understanding engagement, Daniel Hickey and Steven Zuiker (2005) adopt a different approach using situated cognition to define engagement as *engaged participation*. They postulate engagement as a dialectic between participation and non-participation with students involved in negotiating their identity based on the extent to which they become involved in meaningful practices within specific knowledge communities. They argue that, rather than a focus on individuals, their unit of analysis is 'domain knowledge practices' associated with the curriculum. However, typical of previous studies, Hickey and Zuiker used individual sources of data such as student assessments to develop their model of engaged participation.

Two other studies of note inform our understanding of engagement as social. Leslie Herrenkhol and Maria Guerra (1998) used a design to try to move science education away from a transmission model of teaching and learning. They argued that: 'Transforming constructivist models into viable classroom practices has proven to be a significant challenge' (p. 467). They defined engagement as 'discourse practices that extend beyond the behaviour of individual students and involve social and cognitive activity' (p. 439). Working with 4th graders, they compared a classroom where students were assigned intellectual roles and a classroom where students were assigned both intellectual and audience roles. The results of their study indicated that both audience and activity was necessary for engagement. However, they did not speculate about why this might be so and their study was conducted not in a 'typical' class, but in two classes that were specifically set up for the study. In later sections of this chapter, we argue that sociology of emotions provides a framework for making sense of their findings.

Randi Engle and Faith Conant (2002) also used a situated cognition model to frame engagement as disciplinary, based on creating learning environments that support (1) problematising subject matter, (2) student agency to address these issues, (3) accountability for appropriate norms of behaviour, and (4) availability of resources. Engle and Conant identified observable connections between the discipline's discourse, in this case science, and students' actions and argued that if students make intellectual progress, this engagement is productive. They called their measure *productive disciplinary engagement*, a concept also promoted in the National Research Council's (2007) publication, *Taking Science to School*. Engle and Conant recognised the role of emotion and used observations from videotape data to identify some of the behaviours that we also associated with engagement. We agree with them that greater engagement can be inferred both from the level of substantive contributions that students make when a topic is under discussion and the ways in which students attend to each other. We argue that the sociology of emotions provides a framework for this analysis.

Moving from the Individual to the Collective: Emotional Engagement as Social and Temporal

Historically, emotional engagement has been measured using survey or self-report instruments and has been mainly associated with interest. For example, Connell et al. (1995) used self-reports to identify self-perceptions of perceived competence, autonomy and relatedness that were hypothesised to affect student engagement. While these measures can serve to identify aspects of individual student engagement, it could be hard to draw implications that could guide changes in teacher practices for several reasons. One issue is that these types of measures address aspects of a student's engagement at the particular point in time when the survey was administered, rather than averaging out the fluctuation in emotional engagement through sequences of events in the classroom. Therefore, it is difficult to pinpoint causes of either engagement or lack of engagement.

In addition, by focusing on individual students' self-perceptions, the relationship between collective engagement to individual levels of engagement is not sufficiently addressed. On a practical level, efforts to improve individuals' levels of engagement without accounting for the group interactions can be counterproductive. One example of this phenomenon comes from our own research in an urban school, City Magnet. The students described how, when the teacher tried to promote a sense of competence by assigning tasks that were easily accomplished, students would become embarrassed because everyone knew which questions were easy (Olitsky 2005). Just surveying the students' emotional engagement at a single point in time would be misleading, because the same student might report low emotional engagement after being given an easy question, yet high emotional engagement after successfully explaining a new concept to a peer. Self-reports could therefore be faulty measures because any student's sense of competence, autonomy or relatedness is deeply embedded in the day-to-day context of classroom interactions and their implications for emotions. An alternative approach to surveys would be to attempt to understand the contextual variables that inform fluctuations over time in the levels of engagement of both the individual and collective.

A recent study did address the temporal nature of engagement, investigating how emotional engagement varied with activity structure (Uekawa et al. 2007). Study methods included classroom observations, focus groups and the Experience Sampling Method (ESM), based on Mihaly Csikszentmihalyi's (1990) *flow* theory of engagement, to measure engagement in real time as students were asked to record their cognitive and affective responses at specific times. We find this work resonated with our view, because it acknowledges that levels of engagement change depending on context.

We have worked to develop research methods that can help us to investigate the role of classroom interactions in providing the context that informs student engagement. Following Erving Goffman (1959), we understand an interaction to be an act between members of a social group. A focus on interactions allowed us to identify segments of lesson sequences when engagement was a more obvious feature of the classroom. In addition, we situated classroom interactions within events over a longer timescale. In this chapter, we draw on examples from studies that we conducted to illustrate the importance of examining the social aspects of engagement over time, with an understanding of the ethnographic context. Both of the class contexts that we describe in this chapter are unusual in that students were more engaged than had been observed previously as demonstrated by changes in student participation, including their use of canonical science language.

An example of a change in student action that could only be recognised because of prolonged involvement of the researchers with the classroom context involved Sherez, an African American student. She was a significant player in the presentation of a series of science demonstrations designed to show that air was made of molecules that had volume even though these molecules could not be directly observed (Milne and Otieno 2007). In the first instance, when Sherez came to the front of the room to carry out a demonstration, she took 6.5 seconds to reach the front of the room where the demonstration was to be performed. In the demonstration, Sherez inverted a cup containing a scrunched-up piece of paper at its bottom under water and the paper stayed dry.

Sherez's actions were significant, not just for her, but also for the other students in the class. From previous observations of class interactions, we knew that, up to that point, Sherez had not been able to identify much chemistry that was of interest to her. At first, her participation in the first inverted cup demonstration was almost a risk-taking behaviour because she had to weigh any possible loss of social capital with other students against participation in the demonstration. Thus, her initial movement was measured, as demonstrated by her slow movement, providing a space for her to assess how other members of the class interpreted her involvement. Equally, her decision to participate became a resource for other class participants. Although we did not realise it at the time, these actions contributed to the emerging collective positive emotional energy of the class. The second time when there was a need for someone to conduct a modified version of the demonstration, following a rich discussion about the observations that could be made from the first demonstration, Sherez volunteered with alacrity and took less than a second to move to the front of the room to perform the new demonstration.

If Sharez had taken a self-report survey of emotional engagement at some point during the class session, the results would be misleading, and the important role of collective emotional engagement could be missed. If taken towards the beginning of the period, her answers might indicate that she was disengaged and, if taken towards the end of the period, her answers might indicate engagement. However, the answer to such questions would not tell us how engagement-related behaviours, such as the speed at which she came to the front and her verbal participation, changed over time depending on the overall levels of engagement of the class or how these actions became a resource for other students. Through observing interactions, it became apparent that, as students became emotionally absorbed in an activity, like the demonstration and the ensuing discussion, Sharez's behaviour changed. Without a focus on collective engagement, the significance of these separate observations would not be recognised.

Another example for the need for long-term study of classroom interactions involves Carla, a student at City Magnet school, who usually did not volunteer to participate in whole-class discussions and describes herself as not being good at science. However, when watching her peers at the board complete problems involving the balancing of chemical equations, she frequently offered helpful comments to them. Like other students in the classroom, she described the activity of balancing equations as 'fun'. This student might score as disengaged on a general self-report survey but, based on her behaviour and on interviews, her levels of engagement in the classroom varied with the activity and changed throughout the year.

In closely analysing both transcripts and videotapes, it became apparent that her participation changed in response to the collective mood of the class. There was a general pattern in which, following a series of interactions when students supported each other's work and there was a sense of solidarity and common rhythm, she was more likely to participate, sometimes using canonical science language. Following a series of interactions when students were not collectively engaged, or when students made negative comments about each other's attempts at participation, she was often either silent or made off-task comments. In studying this classroom over the course of a year, it became clear that her engagement was contingent on her level of confidence which, in turn, emerged from collective emotional experience. Without long-term observation of participation in the classroom, it would be difficult to discern these types of patterns.

As these two examples illustrate, it is crucial to focus on how engagement evolves over time within the social setting of the classroom in order to understand individual students' engagement-related behaviour, affect and cognition. In this chapter, we discuss how studying social interaction can tell us why and how student levels of engagement change. We argue that a social perspective is important in order to plan for positive changes that will result in the engagement of more students in science classrooms.

The Primacy of Emotional Engagement: Theoretical Perspectives

In this section, we delve more into social theory and recent studies in order to understand the relationship between collective and individual engagement. We attempt to formulate a perspective that can account for changes in engagement over time, address the dialectical relationship between the individual and the collective, and elucidate the interrelationship between different dimensions of engagement. We argue that emotional energy (Collins 2004) is a necessary ingredient for engagement, and that its presence within classroom interactions supports student learning and participation.

Some recent studies aimed at understanding inequalities in schools emphasise the importance of a social perspective on emotional engagement, and the impact of emotions on student behaviours. For example, Rowhea Elmesky (2001) and Gale Seiler (2002) found that when students' cultural capital is not valued in science classrooms, students perceive strong boundaries between their own knowledge, values and dispositions and the cultural enactment of school science. Negative emotions ensue when this occurs, and this interferes with learning. They recommend that science curricula be changed in order to be more relevant to the interests of students in low-income urban areas. In other words, rather than focusing on why an individual student is disengaged, efforts should be made to engage the class as a whole using knowledge of students' culture in order to increase curricular relevance and encourage expression of cultural dispositions. In doing so, students begin to feel more positively about their participation in science, with the implication that positive emotions lead to greater cognitive and behavioural engagement. In another study, Elmesky and Seiler (2007) found that interest in science among urban African American students increased due to collectively generated emotions resulting from science activities that facilitated students' enacting their cultural dispositions towards movement expressiveness.

In the sociology literature, the term 'engagement' is less common than in the education research literature, but there are other concepts that have a close correspondence. Mihaly Csikszentmihalyi's (1990) concept of 'flow' is used to explain when students are caught up in an activity, absorbed and engaged. He writes that students experience flow when there is a match-up of the level of skill and the type of task, so that students are challenged enough to find the task interesting, but not so challenged that the task seems impossible and they become frustrated. Engagement is relevant here, as one of the crucial aspects of flow is the emotions that students experience during a particular task (e.g. whether they are frustrated or confident). Flow, however, as it has commonly been applied, retains an individual focus in science education research studies even though we are of the opinion that flow can also be experienced collectively. In the classrooms in which we worked, we found that students were more willing to engage with a difficult task if they were involved in a collective experience that generated positive emotions, and less likely to engage with an appropriate task if the collective emotional engagement was absent.

We also find that the concept of flow offers only a partial approach to understanding when and how students become engaged, because there are many activities that offer a particular student a level of challenge that is appropriate to his/her skill. Appropriate challenge can be a precondition for engagement, but a theory of engagement also needs to account for why a student would become absorbed in one appropriately designed activity rather than another. Based on our research, we have come to see the role that collective emotional engagement plays in influencing students' becoming cognitively engaged in particular science-related topics or tasks.

In working to understand collective engagement, we draw on the concept of *emotional energy* (EE) and interaction ritual (IR). Collins (2004) explains that EE is the basis of why people engage in particular activities, join particular groups or develop particular identities. He argues that people are EE seekers, choosing courses of action based on their anticipation of the emotional pay-off from participation in solidarity-building interaction rituals. Collins' work emerged from Émile Durkheim's (1965) writings regarding how interaction rituals solidify group ties. He describes ritual as 'a mechanism of mutually focused emotion and attention, producing a momentarily shared reality, which thereby generates solidarity and symbols of group membership' (2004, p. 7). IRs are characterised by bodily co-presence, a build-up of mutual focus, the development of a common mood, an 'entrainment', or coordination, of body movements and speech, shared experience between participants on both an emotional and cognitive level, and boundaries to outsiders.

Apart from feelings of solidarity and an increase in positive feelings associated with the group, successful IRs also support focus on the symbols that circulated in the interaction. Symbols that are both exchanged and created become invested with emotional energy, and can be used later to generate successful IRs with others who find these symbols similarly charged. For example, after a rousing political speech, when attendees get caught up in coordinated cheering, the participants can become energised, be more likely to display signs in favour of the candidate, and be more likely to participate in the campaign. Another way to put this is that they become engaged in the political process.

Like symbols, concepts and knowledge can become invested with EE through being invoked in successful IRs. These include the ideas, concepts and language that circulate in science classrooms. The implication is that, if classroom interactions are characterised by solidarity, emotional energy will become invested in the science-related symbols and participants will be drawn to talking about science with teachers and peers. In other words, whether students choose to come to the front of the board to do a problem or carry out a demonstration depends on their anticipation of emotional pay-off for doing these things – whether they believe that the interactions will result in high levels of EE. Kenneth Tobin (2005) argued that head nodding, humour, eye contact, body orientation, overlapping speech and the completion of each other's sentences are behaviours associated with synchrony that support the emergence of emotional engagement. While acknowledging the cultural nature of some of these behaviours, our classroom experience indicated the veracity of Tobin's general argument. From this stance, emotional engagement is primary, and informs the behavioural and cognitive aspects of engagement, rather than three separate continua.

We have been critical of methods of data-gathering that rely primarily on self-reports. Collins' theoretical work suggests that engagement is to be understood as a social occurrence embedded within interactions. Taking this view, a person's engagement in an activity needs to be understood as the culmination of both short-term and long-term previous interactions with the symbols and groups that are relevant to that activity, illustrating the limitations of time-static measures, such as self-reports which do not address how individuals are the outcomes of situations.

The Role of Collective Emotional Engagement in the Emotional, Behavioural and Cognitive Engagement of Individuals

Collins (2004) describes how EE is not only invested in symbols, but also resides in individuals who have different levels of EE that they bring to interactions. These levels of EE are expressed as pride, confidence, shame, shyness or other characteristics related to how a person approaches others. Yet these characteristics are not 'personality traits' that are static, but instead they fluctuate from situation to situation based on each person's prior experiences with IRs in particular contexts. Collins explains: 'Pride is the emotion attached to a self energized by the group; shame is the emotion of a self depleted by exclusion … nonverbal and paralinguistic measures of pride and shame can be useful as measures of high and low EE' (p. 120).

An implication of this perspective on the transferability of EE from IRs to individuals is that socially shared emotion influences individual engagement. After successful IRs that result in participants leaving with high levels of EE, these participants are likely to approach similar situations in the future with greater levels of confidence. Confidence can be seen as an indirect measure of individual emotional engagement, as it is similar to the 'perceived competence' that is used in self-report measures in other studies of engagement. This emotional engagement in turn affects behavioural and cognitive engagement in that people who are confident in a specific situation are more likely to participate actively (behavioural engagement) and engage with the content (cognitive engagement).

Collins (2004) provides an example that can illustrate the relationship between the three dimensions of engagement in his discussion of why people sometimes choose not to speak in public forums. He describes how sometimes, in academic lectures, there is a long pause before the audience offers any questions:

> The subjective experience of members in the audience at that moment is that they can think of nothing to say. Yet if the pause is broken – usually by the highest-status member of the audience asking a question – multiple hands go up. This shows that the audience was not lacking in symbolic capital, in things to talk about, but in emotional energy, the confidence to think and speak about these ideas … not that they had nothing to say, but that they could not think of it until the group attention shifted to the audience. (p. 72)

This 'group attention' changes the focus of the IR, so that the audience becomes more central, which raises participants' EE levels and therefore their confidence to speak.

In Collins' example, as well as in our own observations of science classrooms, a multidimensional model of engagement with three separate continua is not sufficient for understanding how people become engaged. Instead, we believe that collective emotional experience is primary. Our studies show that high levels of EE lead to confidence and other expressions of emotional engagement such as pride, which then support students' active participation through activities such as volunteering to help with a demonstration or using canonical science language in developing an explanation.

In applying these ideas to science classrooms, a student's demonstration of science knowledge might not be a result of students' personality traits, general interest in science, or knowledge of the material. We argue that instead, the participation is an outcome of collective emotion generated in IRs. One relevant factor, similar to Collins' example of the academic lecture, is whether the focus of group attention is on the teacher or on the 'audience' – the students. Referring to the earlier example of Carla who participated more frequently during the unit in balancing equations, her increased participation was not because, in some abstract way, she believed that she was better at balancing equations than she was at other tasks in science. Instead, it was because, during interaction rituals associated with balancing equations, there was a shift in attention from the teacher to the students when the students solved problems at the board with the support of their peers (Olitsky 2007). The collective emotional experience generated when students helped each other during balancing equations IRs contributed to increases in levels of confidence for many students, and therefore their willingness to engage with the material on a cognitive level.

An important feature of this situation is that the teacher's efforts to help her students learn the material were effective because she provided a structure with the goal of establishing a positive emotional starting point, an essential ingredient for student success. According to Collins (2004), part of this emotional experience involves the establishment of a context that is well bounded and has a mutual focus that effectively secures the group's attention. Balancing chemistry equations, science demonstrations or any shared experience can provide such a starting point. The initial question that can frame planning for such an IR is not a cognitive one (e.g. 'What is the prior knowledge that students bring to a learning context and how can

I access this knowledge when teaching this material?'), but an emotional one ('How can I try to optimise the initial emotional experience for students when introducing this material?').

Certainly Ms Loman's providing students with an effective method for approaching problems involving balancing equations was essential for the IR to take place, as it would not have occurred if the students had no idea how to approach such problems. We are not arguing that these skills are unnecessary, and that it is only the emotional component that matters. Instead, we are arguing for the complementarity of emotion and skills in order for the instruction to be effective. In teacher education programmes, attention is often given to assessing student knowledge and drawing on this knowledge in order to design instruction. Our research suggests that, in the beginning of a school year or a unit in which new material is introduced, it is also vital to provide initial emotionally engaging experiences that establish boundaries around the class as a group.

In Tracey's classroom, the shared observational experience of students in the class as they participated in the science demonstrations about the gas laws allowed them to feel confident that each of them had access to the same experiences and therefore could make equally valid observations. Even if a specific student was not one of those to propose an explanation of the observed phenomenon using molecules and atoms, he/she felt more confident about his/her ability to make connections between the explanations and these shared observations (Milne and Otieno 2007). Science demonstrations are focused whole-class interactions that are constitutive of a fluid type of ritual that exists on a continuum between social situations and formal rituals. They are structured by some ritual elements, such as mutual focus, group assembly, barriers to outsiders and shared mood, but the application of these elements depends very much on the context and on the actions of agents including students and the teacher. Through use, demonstrations became ritualised as IRs and help to build student expectations that something interesting or contradictory was going to happen and contribute further to positive emotions in the classroom.

We have described IRs that are solidarity producing. However, other rituals, such as the 'order giving' rituals of some typical classrooms, can support a gain in EE for the order giver and a loss for the order taker, without actually increasing feelings of group membership (Collins 2004). One example would be a lecture or reprimand by a supervisor. After experiencing such a loss of EE and, therefore, shame, individuals might shy away from these groups and the use of symbols invoked during those interactions. A student who experiences science classrooms as order-giving rituals, in that teachers or other students do not accept her/his contributions as worthwhile, can carry low levels of EE into future interactions involving science. An apparent lack of confidence or interest can present as an 'individual' characteristic, but it is a product of the situation (i.e. an outcome of low levels of EE generated in previous interactions). Another route to an individual's loss of confidence is feeling excluded from an IR in which most of the participants experience solidarity and raised levels of EE. Participation in a dynamic conversation in which one does not know anything about the topic could result in this type of EE loss, thus highlighting the importance of science demonstrations as a shared experience in Milne and Otieno's (2007) study.

From the teacher's perspective, the confident student who is charged with EE appears to be more engaged. That student will freely inject his/her contributions with the expectation of solidarity, which Collins (2004) describes as 'smooth flowing rhythmic coordination in the micro rhythms of the conversational interaction; it gives the feeling of confidence that what one is doing, the rewarding experience that one's freely expressed impulses are being followed, are resonated and amplified by the other people present' (2004). Similarly, if the whole class, or even most of the class, is feeling high levels of EE and is confident in that setting, then it would seem to a teacher that the class is collectively engaged. When teachers describe a 'good discussion', in which most of the students provide contributions, take risks with their comments, ask questions and develop explanations, it is likely that most of the students anticipate high levels of EE in these interactions and so are more willing to speak. Other contexts in which we have observed this happening include students giving each other high-fives when they successfully complete a complex task, such as working out the chemical formula for a compound or completing a half-life problem (Milne and Ma 2008). The primacy of collective emotional experience and the power of confidence can be used to help in understanding the differences in engagement that were observed by the researchers conducting these studies.

An assumption that underlies some of the previous research on engagement is that past experiences of success at an activity will lead to a person's confidence in his or her abilities. The implication is that confidence emerging from success will contribute to the student being willing to verbally participate in class discussions, come to the front of the class to use the chalkboard or demonstration, use science language, or exert effort on a test. Yet our research has shown that prior success might not be sufficient for the emergence of either collective or individual engagement. Rather, the accompanying emotions are more predictive of engagement. Positive emotions can accompany actual success, but not always. For example, in City Magnet during the balancing equations, it was the harder problems at which students were initially *unsuccessful* that elicited student cooperation and positive emotions, rather than the easier problems that students solved successfully (Olitsky 2007).

Interaction Rituals and Engagement: Implications

Our studies have shown how collective emotions generated through successful IRs have transferred to individuals' increased confidence and pride, and have led to changes in different dimensions of student engagement within two science classrooms in Philadelphia. An implication of this research is that collective emotions can have a powerful impact on collective engagement and on individual identity, class participation and learning. Conversely, when individuals develop increased pride and confidence related to science participation, IRs in class have a greater chance of success. The similar findings about engagement from two very different schools, one selective and the other an urban neighbourhood school, support the primacy of the social and emotional aspects of engagement in influencing what has typically been described in previous research as cognitive engagement.

For teachers wishing to foster positive classroom changes, these studies suggest the need to provide a shared experience that is available to all within a context that has clear boundaries and excludes outsiders. Establishing this type of situation allows the development of group co-presence that supports students in monitoring each other's emotional states. From this structure, it is possible to build an intensity of group emotion evidenced by synchronous shared observations and explanations, students completing each other's sentences, overlapping or latched speech between participants and shared excitement. In a classroom, positive emotional energy builds from successful interactions into interaction ritual chains that support cognitive and behavioural aspects of engagement. This energy is available to everyone in the class who becomes caught up in the collective emotional experience.

Evidence of student engagement can include actions such as eye gaze, overlapping speech, entrainment in conversation and shared action. Cognitive aspects of interactions indicative of engagement can include participation in the use of language associated with science knowledge, an interest in asking questions, a willingness to focus on observation as well as explanation, and a desire to work together to construct science understanding. Emotions are experienced internally and exhibited so that they are available to others. We have argued that establishing collective engagement requires specific classroom structures. However, the agents of teacher and students are central to the establishment of interaction ritual chains and emotional energy that are essential for the expression of collective and individual student engagement.

Going back to Herrenkhol and Guerra's (1998) study, their definition of engagement was based primarily on cognitive types of actions that involve 'monitoring one's own comprehension of another's ideas, coordinating theories with existing evidence, and challenging the claims put forth by others' (p. 441). Participation in these types of tasks requires risk-taking in that students need to be willing to share their own conceptions and ideas. They, therefore, require some level of confidence in engaging in science discourse. We argue that it is the collective emotional experience that leads to individual student confidence, thereby making cognitive engagement possible. The link between confidence and these higher-level cognitive tasks further lends support to our argument that emotional energy provides the basis for cognition and should be the initial focus of educational practice.

Additionally, the view of engagement as stemming from collective emotions can add an important piece to perspectives of engagement that portray it as integrally tied to an individuals' participation within collective, goal-oriented activity, such as Engle and Conant's (2002) *productive disciplinary engagement.* An individual's participation within a discipline, which is a similar conception to the 'community of practice' that Jean Lave and Etienne Wenger (1991) describe, requires not only skill, but also the desire to be part of the group and manipulate its symbols, the confidence that one can participate in this group, and an identity associated with this group. All of these are outcomes of high levels of EE. An individual, therefore, needs to have participated in previous solidarity-producing interactions in order to be imbued with the EE that is a necessary precondition for productive disciplinary engagement. Similarly, Palincsar, Anderson and David (1993) describe the importance of flexibly adapting intellectual roles so that students do not apply science knowledge in a rote manner. Rather, students need to appropriate the science-related symbols and tools for their own use and develop fluency with them. This deep level of participation necessitates positive emotions, as high levels of confidence are necessary in order to take the risk of manipulating symbols in creative ways.

Overall, we argue that collectively generated emotions are a precondition to the different dimensions of engagement required for effective science teaching and learning. These emotions affect individual levels of EE, which have implications for student confidence and, therefore, learning. Conversely, when individuals emerge from IRs with high levels of EE, they can help initiate or participate in future solidarity-building IRs related to science. Assumptions that sometimes permeate some academic and non-academic discourse include views of individual students as either 'engaged' or 'disengaged', and views of subject matter as either interesting/relevant or uninteresting/irrelevant. In contrast, our research supports a focus on interactional situations and how EE transfers between the individual and the collective.

We argue that attention to emotion-related outcomes needs to inform all aspects of instruction. Individuals who emerge from series of solidarity-producing classroom interaction rituals will develop the confidence, desire and energy to expend the effort in order to engage with science content and to participate in communities centred on science.

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Chapter 3
Identity-Based Research in Science Education

Yew-Jin Lee

Introduction

As one of the fastest growing areas in the social sciences, identity-based research has likewise begun to make its presence felt in science education. Because of its philosophical richness, the concept of identity, as well as closely related notions of subjectivity, self, and selfhood has generated a diverse and typically puzzling array of studies for the newcomer. Identity-based research is nonetheless exciting for it is associated with agent-centered development, a sense of belonging and affiliation, and engagement in learning, which are all right in the middle of what we hold dear in education. Identity is, as Anna Sfard and Anna Prusak (2005), p. 15) put it, the "perfect candidate for the role of 'the missing link' in the … complex dialectic between learning and its sociocultural context." This chapter does not seek closure but, instead, attempts to provide a rough guide of the terrain by examining some of the theoretical roots of identity and how it has energized science educators in recent years. Specifically, through the lens of identity, we better appreciate learning from a sociocultural perspective and the contingent processes of making different kinds of people and places.

An accessible vantage point for unraveling identity is to consider how it has been handled in psychology and sociology. Risking oversimplification, the former has generally emphasized internal or essentialist aspects of identity as characteristics of individuals, whereas the latter has understood it to be a collective property of people engaged in social interaction (Côté 2006). Based on these dichotomies, there emerge various epistemological and methodological conundrums, including to what extent identity is reflexively constituted by agents or their social groups and in what manner (e.g., biology, talk, rules, schema), whether the linguistic/postmodern turn holds any implications for determining identity (e.g., changeable, multiple, or indexical selves), and the salience of our

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abstract theoretical models of identity vis-à-vis lived experience across time and space (Hammersley and Treseder 2007). Indeed, when temporality is factored in, it adds yet another layer of complexity as different aspects of identity formation seem to run at different speeds while other aspects remain invariant (Lemke 2000).

Some authors have understandably grown disdainful of identity-based research because of the sheer multiplicity of meanings and cognate terms, which allegedly has resulted in fuzzy thinking. The term "identity" is absent from the indices of the first *Handbook* in this series published over 10 years ago, as well as those by Sandra Abell and Norman Lederman (2007) and Dorothy Gabel (2004). Most educators, however, are comfortable with taking identity as being a subjective sense or definition of oneself, and the corresponding recognition of being a particular kind of person, an intersubjective component. Again, the degree to which one's identity changes with respect to the social situation and how much an individual is defined by the latter depends on one's starting assumptions about the mutual constitution of agency and structure.

Without trivializing these problems, it might be fruitful to heed Gilles Deleuze's adage and question about what identity can "do" rather than attempting to define what it "is." Besides proposing a popular composite model of identity that mixes four essentialist and nonessentialist dimensions, Gee (2000–2001) explains that using identity as an analytic lens can help shed light on critical issues of fairness and access in education. Scholars concerned with gender disparities and inequalities in science have thus not been slow to pick up on the theme of identity (Brotman and Moore 2008). Building upon James Gee's (2000–2001) fundamentally sociocultural model, anyone possessing a *science identity* would signal (1) competence, (2) performance, and (3) recognition (Carlone and Johnson 2007). Allied to this and a recurring motif in this chapter, it is evident that if teachers can support student science discourse (i.e., talk and behavior) use in classrooms, this assists in developing their *academic identities* in science and mastery of scientific literacy (Reveles and Brown 2008). This presupposes teachers identifying themselves as science teachers who are competent and like science in the first instance (Helms 1998; Luehmann 2007). Insofar as identity issues are implicated during personal meaning-making, success, and emotional energy in science learning (Olitsky 2007), having any identity that is valued or powerful in official school contexts is contingently shaped by other meta-factors such as race, class, and gender. Schools do provide a significant sense of place and resources for (science) identity development among students, although this transformation need not necessarily be affirming or positive over the short or long term. Other activities and locations are similarly pivotal sites for identity formation among youth, which science educators can co-opt for planning better learning experiences and engagement with science (Eisenhart and Edwards 2004; Rahm and Ash 2008).

Theoretical Frameworks in Identity Research

Because ontologies of difference are normative when thinking about science education in the twenty-first century, we ought to expect nothing less when undertaking identity-based research (Roth 2008). Compared to earlier times when identity-based research in science education was closely aligned with investigating student motivation, learning, and achievement from more psychological perspectives (Roeser et al. 2006), the focus has gradually shifted toward adopting sociocultural modes of inquiry because of an increasing acceptance of interpretative paradigms. What perhaps unites sociocultural viewpoints that are myriad within themselves is the denial of "mind" as the pure cogito: ability is better considered as a skillful coordination of people and objects in specific social settings – "knowing" is a performance. Being knowledgeable (or not) is thus equivalent to assuming an identity that is recognized by other members of a community. A review of salient literature from the last decade has shown that the three theoretical frameworks below have been among the most favorably received among science educators.

Figured Worlds and Practice Theories

A remarkable piece of anthropological scholarship, *Identity and Agency in Cultural Worlds* by Dorothy Holland, William Lachicotte, Debra Skinner, and Carole Cain (1998), continues and will continue to exert a powerful influence on identity-based research in science education. The book, almost single-handedly, has developed a model of identity development – *identity-in-practice* – that accounts for both free will and structural constraints at the intersection of shifting social contexts and individual circumstances. Besides stressing how identities are situated achievements, it directs one's attention to how identity is also a verb, something that requires action/work from self and others. A lynchpin in this argument lies in what is called *figured worlds* – "*historical* subjectivities, consciousness and agency, persons (and collective agents) forming in practice" (Holland et al., pp. 41–42). As imagined or "as if" locales that have recognizable social architectures (e.g., teenage romances), figured worlds motivate people to action, existing in a dynamic interplay with identities and human agency. They are populated with their typical agents (e.g., the science geek), appropriate ways of behavior and attached values, which then become heuristics for developing into certain kinds of people. Figured worlds permit or at least inspire a modicum of agency and control in situations that at first sight deny all such privileges. One quickly acknowledges their utility for science educators as tools for redesigning culturally sensitive learning environments with which students desire connecting and that they deem to be integral for their lifeworlds (Kozoll and Osborne 2004). If figured worlds are a generative unit of analysis, how large or encompassing should they be? It would seem that a science classroom can be decomposed into smaller figured worlds, such as individual work, group activities, and whole-class instruction (Tan and Barton 2008). It is not denied that figured worlds seem to be a convenient metaphor or that they overlap with culture (Brickhouse et al. 2006) and communities of practice (Barton et al. 2008), although these questions await final answers. At present, figured worlds have been used extensively by (science) educators who embrace the critical tradition, especially those who work in urban areas (Urrieta 2007).

The social theorists to whom *Identity and Agency* frequently refers range from Pierre Bourdieu and Mikhail Bakhtin to Lev Vygotsky and, above all, George

Herbert Mead. The authors take a middle stance between what they call culturalist (i.e., more structural, anthropological) and social constructivist, for which identity is solely constituted in interaction, in the *positionings* (see Holland et al. 1998, pp. 271–272) involving power, privilege, and rank. Identity is thus viewed as multiple and fluid though not entirely free and unbounded. Identity change both occurs in and is a by-product of the dialectic of past histories (and material circumstances) and the present semiotic signs that people improvise or resist. Sometimes these temporal and contextual *spaces of authoring* are said to occur within a lifetime and might become the next generation's new habitus or cultural artifacts. At this point, identity-in-practice appears to overlap with *practice theories*, which likewise emphasize the dialectic of structure and agency – that tango of interpellation which supports social others/culture/institutions at the same time as its remakes and the parallel manufacture of subjectivities. One can certainly orient toward and pursue certain goals though the outcomes are never guaranteed (Levinson and Holland 1996). For instance, in the process of creating a culture of academic success in an urban Magnet school, both individuals and institutions changed, alienating some players though ultimately achieving a niche for success in science and mathematics (Buxton 2005). Likewise, teachers who are caught up in reform movements face complex positioning and shifting subjectivities as they attempt to fulfill their objectives (Enyedy et al. 2006). Metaphors used here to (partially) capture how the social and personal are integrated have included habitus, history-in-person (Holland and Lave 2001), and lamination (Holland and Leander 2004). Key issues that are now being addressed are whether there are focal or anchoring practices that spawn other practices and social rules, and a call for more fine-grained empirical analyses of the actual mechanisms of practices (Swidler 2001).

Discursive Stances

Language, as preeminent social practice, is inseparable from identity. We use talk to do things and bring all manner of objects, including ourselves and others, into being. At other times, it seems as though the reverse is equally true. Physical objects and phenomena, mental states and identities are spoken into existence by prevailing discourses, which underscores that facet of subjectivity in identity as one being fitted into a mold or social position (Bucholtz and Hall 2005). This dual role of language with respect to identity is what Gee (2005) refers to as the mutuality of "D" and "d" discourses, which finds no conflict with structure/agency frameworks. Defined by immense heterogeneity rather than commonality in theory and methods, identity-based research that relies on discursive stances draws upon a long, albeit kaleidoscopic, record of use in the social sciences.

Whether talk is better regarded as a *resource* or carrier of knowledge and identity labels, as opposed to it being the *topic* of scrutiny itself, it is a useful analytic distinction. Researchers interested in knowing *what* was articulated and the meanings associated with these identity classifications would analyze narratives as a resource, as content to be mined at various levels of organization, such as clusters of science sense-making by students in Bryan Brown (2006) or stories of kids negotiating discrimination, poverty, and science in Angela Calabrese Barton (2003). Those who make thematic discourse as a topic accordingly follow an opposite track by examining *how* people present themselves and make sense of each other and of the rhetorical devices that they (un)consciously use to accomplish these tasks (e.g., constructing expertise during science discussions in Alandeom Oliveira et al. (2007) or signaling science discourse identities in Brown et al. (2006). Thankfully there is no necessity for taking sides because each approach has been very productive. It ultimately depends on the preferences for top-down or bottom-up contextual influences. In the real world of research, there is often an amalgam of these stances mentioned above, such as when grounded theory is used in conjunction with established sociological themes to trace a science teacher candidate's identity changes (Rivera Maulucci 2008) or when elements of narrative theory and discursive psychology explain the life-history accounting of a scientist (Lee and Roth 2004). One fascinating study of nerd girls used communities of practice derived from practice theories and sociolinguistics to show how "nerdiness" was a contested domain and that this identity depended upon linguistic and social factors (Bucholtz 1999). Compared with the other two theoretical frameworks in this section, discursive stances (e.g., those using conversation analysis) enjoy the advantage of being the most empirically founded (i.e.. open to verification by readers as well as being potentially closer to participants' concerns).

Activity Theory

Cultural-historical activity theory, or activity theory, furnishes a substantial set of principles for analyzing social action in everyday life (Roth and Lee 2007). Subjects (those whose perspective are taken) are always understood as motivated toward some Object (that which is to be acted upon). When Objects are absent, there is no societally relevant activity or motive of which to speak. Identity, rather than being an innate property of individuals, is thus an outcome of dialectically engaging in practical activity (Roth 2007a), which has much affinity with practice as *the* unifying methodological element (Cole 1996) and, by extension, identity-in-practice (Wenger 1998). Further, identity development is above all purposeful, a meaningful life project – though not always in favorable settings – that simultaneously is determined by and contributes to social life. Even though leading educators have endorsed activity theory as a means of understanding learning holistically (Kelly 2008), it remains a recent and daunting framework of choice for identity-based researchers in science education. For instance, Wolff-Michael Roth et al. (2004) explained how identities changed as people crossed from one activity system to another, while Roth (2007b) argued that efforts to inculcate scientific literacy and identities without taking into account the emotional-volitional and ethico-moral aspects were doomed. Outside science education, Kevin Leander (2002) showed how classroom artifacts as significant mediators of action served to stabilize one girl's identity as "ghetto." It is also surprising to note how welfare shelters could still afford positive sites for identity formation among homeless youth (Penuel and Davey 1999). Cognizant that some of these studies were performed in challenging urban environments, activity theory offers hope for the future. Being historically created institutions, these too are amendable to the transformative effects of human agency.

Identity-Based Studies in Science Education

In what follows, summaries of three recent identity-based studies give a sampling of the kinds of theories used to uncover identity and some substantive areas of concern among science educators.

Global Identities Among Immigrant Students

Katherine Bruna and Roberta Vann (2007) used critical discourse analysis and a "practice of science" (Barton 2003) perspective to ask how ready science teachers in the USA were to build spaces of hope for all learners. From their ethnographic results, they feared that educators were largely unprepared to draw on their students' funds of knowledge and were also restricted in granting students' control over their learning. Borderland identities in science were not celebrated (Brickhouse and Potter 2001). Seen through a critical episode – a classroom dissection of a fetal pig – this seemingly mundane science experiment took on greater significance as the students came from Mexican immigrant families in the town whose economic wealth depended on the alienating forms of labor supplied by these same meat-packing workers. As much as Linda (the science teacher in the study) showed genuine care, she could not escape positioning her English Language science students as future unskilled laborers for that was the socioeconomic structure (and identities) with which she was most familiar. The science lesson thus became metonymic of global capitalism and privilege, whose uneven effects were filtering down to classrooms and the kinds of people that the students were now, and could be later. In common with the increasingly loud calls for social justice, access, equity, and quality in science education, issues of identity formation among youth were central here and were used as weapons of critique, exposing the underbelly of educational systems (Brown 2004; Tobin et al. 2005).

Positional Identity and Science Teacher Professional Development

Positional identity or positionality (Holland et al. 1998) is the sense of one's relative place in the world shot through with power, privilege, access, and constraints that have historically stemmed from various social markers such as race, gender, ethnicity, age, and economic status. While it is acknowledged that these cultural worlds influence how a person views the world and is defined by others, we do not fully comprehend how they shape teachers in terms of their everyday classroom decision-making, their sense-making of life experiences, and their professional learning and career goals, which is the subject of a study by Felicia Moore (2008). Drawing on a sample of three African-American secondary science teachers in a rural district, Moore (2008, p. 685) examined how positional identity could open our minds to understand "teachers on a personal level, their classroom practices on a practical level, and their professional development on a professional level." Aligned with critical feminist thought, there was no single positionality expressed by these teachers, even though they came from rather similar social backgrounds and ethnicity. Cultural-historical worlds collide, overlap, and intercept in diverse, random ways. In terms of teacher professional development implications, accounting for positional identity, with its focus on sense-making across one's past experiences, nurtures sensitive and personal ways of teaching and relating to students, especially those who are marginalized (Proweller and Mitchener 2004).

Differential Identities from a Common Curriculum

Researching the experienced curriculum involves asking what it is like to learn in *this* environment and it foregrounds the feelings of teachers and students in their learning journey. With regard to gender differences in science learning (Brickhouse et al. 2000), these questions of meaning have been examined using concepts from cultural anthropology by Heidi Carlone (2004). Part of an ethnographic study of a reform-based physics curriculum, the author takes pains to show that just as some embraced the new pedagogies, some female students contested the associated science identities that it promoted. Replacing the identity of "listener, memorizer, and recipient of knowledge" (p. 404) with that of problem-solver, hard-worker, and generator of knowledge was simply too great a loss of identity (c.f. Black honors students acting White in Andrew Gilbert and Randy Yerrick (2001)). This resistance is unusual as the students were largely White, upper-middle-class teenagers whom we would expect to subscribe to student-centered teaching. But we are told that there was a culture of achievement in their community that narrowly defined success in terms of academic performance. This ideology, of course, conflicted with the inquiry goals of the physics curriculum, which eschewed didactic teaching and instead encouraged open-ended experiments by student groups. In the end, the report card for this curriculum here was mixed: some girls did not contest the circulating cultural myths in which science was seen as difficult or that scientists were superintelligent males. Yet, other girls responded to the new ways of learning and crafted new science identities for themselves. The power of this micro–macro approach in practice theory is that it offers reasons for the differential choosing or refutation of identities and learning trajectories by agents. For the science educator, it demonstrates how both reform and implementation processes are fraught with unintended responses, which truly "complicates our quest for gender-fair science" (Carlone 2004, p. 392).

Conclusions

For decision-makers in education, identity-based research of the kind articulated here presents frustratingly little in terms of "hard data" from longitudinal or large-scale studies to guide change. The uncertainties surrounding the theories of identity are legion and present further obstacles for policy and concrete translation into curriculum or programs (Brotman and Moore 2008). We are still unsure if it is necessary to change identities in order to learn science, the affordances that science practices allow for person-making, and the real, material consequences of identity as a construct (see Moje et al. 2007). So what does the crystal ball augur for identity-based research in science education? A decade ago, Barton sensitized educators to the situated nature of *all* pedagogy, how it was located within historical and sociopolitical currents that made "representation in science (what science is made to be) and identity in science (who we think we must be to engage in that science)…central" (Barton 1998, p. 380). This observation is still pertinent and it is clear that identity-based research is suited for interrogating these problems for it refuses to dichotomize the making of people from their learning and milieu. The concept of identity places tremendous power in the hands of science educators for it encapsulates within itself literally life-changing educational means and ends. Identity as being inveighs against deficit philosophies of learning that devalue differences, whereas identity as becoming invigorates our struggle for a better world that is not unattainable. Starting from our current troubled (and troubling) spaces called classrooms, where we literally coerce youth to occupy, identity-based research can help us to transform them into places that youth want to inhabit for the long term and in which they invest their talents in science.

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Chapter 4
Diverse Urban Youth's Learning of Science Outside School in University Outreach and Community Science Programs

Jrène Rahm

To fully grasp students' scientific literacy development, we have to better understand the range and repertoires of cultural practices they participate in (Kris Gutiérrez and Barbara Rogoff 2003). These include, for example, afterschool science programs, science leisure activities, museums, summer science camps, science activities in community youth programs, in their families, and in school. Yet, Robert Halpern (2006) makes the point that to date few studies have explored children's and youth's navigations and learning trajectories within and across such practices, in part due to the complexity of children's out-of-school lives' development, and the difficulty in establishing how participation in diverse science activities adds up and contributes to students' scientific literacy.

As the matter currently stands, we know that engagement with science in such settings and practices makes a difference in terms of youth's academic standing and leads to increases in their levels of scientific literacy as reported by Mary Atwater, John Colson, and Ronald Simpson (1999), while Kathleen Fadigan and Penny Hammrich (2004) document positive effects in terms of an interest, positive attitudes, and confidence in science, as well as higher chances of pursuing career trajectories within the sciences. Similarly, Lisa Bouillion and Louis Gomez (2001) assert that university-based outreach science programs show positive outcomes in terms of students' understanding of the nature of science and scientific inquiry, while also opening up participants' eyes to science career possibilities (Bell et al. 2003). Furthermore, community science programs that respect youth for who they are play a crucial role in youth's identity work as potential insiders to science, offering them with opportunities to co-construct science and become agents of science (Angela Calabrese Barton 2007, 1998). To use science as a means to an end rather than an end in itself is what often distinguishes such programs from school science. Yet, Patricia McClure and Alberto Rodriguez (2007) argue that still more needs to be known about why, how and for

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whom such programs make a difference, and in turn, how they constitute scientific literacy development of our students and may inform current practice.

In this chapter, I follow-up on that question through a brief exploration of a university outreach program and a number of community science programs driven by youth science. Grounded in sociocultural theory, I summarize briefly youth's forms of engagement but also identity work and positioning within science in these settings. Yet, I first step back in time and offer a brief historical account of informal science practices.

A Brief Historical Account of Informal Science Practices

The landscape of informal science practices has become extremely complex and the use of the term informal science itself problematic. I invoke it here in reference to Valerie Crane's discussion of it in one of the first books on the issue, offering an overview of the field when it was in its infancy (Crane 1994). At the time, informal science learning referred to learning activities that happened outside of school and that were not driven by an academic focus per se, that were voluntarily sought out, and that competed with other leisure activities that the children and youth could engage in during nonschool hours.

Heather Johnston Nicholson, Faedra Lazar Weiss, and Patricia Campbell's (1994) overview of community-based programs suggests that these institutions included math and science activities for a long time, typically in an unself-conscious way. In other instances, the poor quality of school science instruction led to a conscious effort to eventually make science the primary objective of such programs. Table 4.1 offers a typology of programs, which the authors suggest is still useful today. Science discovery programs are the ones meant to offer hands-on science activities to children, youth, and sometimes their families.

Through engagement in science activities, such programs aim to influence the participants' attitudes toward science and to increase their self-confidence as learners of science while also attempting to make science accessible. The overall message "science is play" unifies these programs (Nicholson et al. 1994, p. 119). In contrast, science camps that are part of the college and university outreach fabric or run by businesses and sometimes also community organizations, tend to recruit academically strong students for the science pipeline. Their message differs somewhat and may be summarized as follows: "[S]cience or math is work but you can be good at it and enjoy it" (Nicholson et al. 1994, p. 139). It is assumed that through engagement in intellectually challenging and authentic science, in some cases at the elbows of scientists and their graduate students, the participants' confidence in school science will increase and the youth can come to see themselves as potential insiders to the world of science. In turn, the career programs ensure that the now interested student stays in the scientific pipeline. In addition to opportunities to engage with science, such programs often also entail a mentorship component to ensure progress along a learning trajectory in science. Hence, such programs are typically extensive and offer some form of support over longer periods of time than science discovery programs and science camps (Table 4.1).

Table 4.1 Typology of informal science programs

Types of programs	Goals of programs	Examples
Science Discovery	To offer practical, hands-on science experiences to children, youth and their families that are enjoyable. Message: "science is play."	– Hands-On Science Outreach – Operation SMART (for girls only) – Linkages for the Future – 4-H Series (Science Experiences and Resources for Informal Educational Settings)
Science Camps (Associated with Community Organizations, College and University Outreach, Businesses, etc.)	An intensive encounter with science that will increase participants' confidence that they can succeed in science in school and become insiders to the world of science. Message: "science or mathematics is work but you can be good at it and enjoy it."	– EUREKA! (for girls of color only) – TERC Environment Network Project – Mathematics & Science Upward Bound Programs
Career Programs	Multifaceted support systems designed to ensure that students stay in the scientific pipeline. Extensive programs, support, and guidance offered over time.	– Project Interface – MESA (Mathematics, Engineering, Science Achievement Program) – Science Skills Center – Project SEED (Summer Educational Experiences for the Disadvantaged)

Adapted from Nicholson et al. (1994)

Ideally, all children and youth, irrespective of who they are, should have access to these three kinds of programs over the course of their childhood. Yet, accessibility to that infrastructure poses a serious challenge for diverse youth living in poverty, translating into the persistence of negative attitudes and low achievement scores in science as well as the underrepresentation of them in science (Calabrese Barton 2007). A study that gathered African-American parents' perspectives on informal science education further confirms that even when informal science practices are available in the community and part of the communities' infrastructure, they can remain inaccessible due to racial oppression. In the case examined by Jamila Simpson and Eileen Carlton Parsons (2009), the program relied on schools for advertisement, yet their calls for participants did not reach all students. Instead, many families heard about the program from other parents, coworkers, and children who convinced them of its value. When examining what the parents were hoping to find in such a program, it went beyond hands-on science that was related to real life and their community. They valued opportunities that nurtured their children's identity as African-American youth, such as the exposure to African-American role models in mathematics and science, to give one example.

Melvin Delgado (2002) identified four elements of accessibility that need to be considered when exploring the new frontier settings of science and youth development, as he termed them at the time, namely: (1) geographical, (2) psychological, (3) cultural, and (4) operational accessibility. Operational and geographical accessibility pose barriers more often for girls than boys, preventing their participation when their safety is questioned due to the timing of the program (returning in the dark) or due to the physical location of the program (Froschl et al. 2003). Simpson and Parsons (2009) describe issues related to psychological accessibility such as feeling accepted, respected, and physically safe in a setting. In addition, the study speaks to the importance of cultural accessibility in that the parents were searching for experiences that validated and nurtured their children's ethnic, racial, social, class, and gendered identity.

Clearly, much work remains to be done to better understand the many dimensions of accessibility to the informal educational infrastructure. At the same time, some examples exist of programs that have been successful in bringing outsiders in and that are worth exploring in detail. The first kind of program I examine is a Math and Science Upward Bound Program, one form of university outreach that has existed in the USA since 1990 (Olsen et al. 2007). Such programs, by definition, purposefully target diverse youth living in poverty and/or being first-generation college bound. Community science programs make up my second case, programs that start with youth rather than science and that consciously and continuously attempt to bridge the worlds of youth and science.

Two Kinds of Programs: Outreach and Youth Centered Programs

I begin with a look at identity work and learning trajectories in a university outreach program and underline the contradictions participants experienced over time as they engaged in science. I then explore what it means to engage in meaningful science in a number of community programs and how such may translate into more expansive and inclusive notions of science that challenge our long-held notions and practice of elite science. The two sections then lead to a discussion of issues that need to be taken serious in an era defined by a proliferation of informal science programming yet also disillusionment with science education.

Programs Reaching Out to Youth: The Case of Math and Science Upward Bound

University outreach programs can be roughly divided into two kinds: (1) those that offer authentic science activities to academically strong students and focus on helping them understand the true nature of science through engagement in authentic science at the elbows of scientists; and (2), those that aim to increase ethnic diversity on university campuses through enrichment programs for diverse elementary and high school students, sometimes in combination with prep work for college (Rodriguez et al. 2004). I focus here on a Math and Science Upward Bound program that did both. As summarized by Edward McElroy and Maria Armesto (1998):

> Upward Bound intervenes in the lives of underachieving low-income high school students by uplifting and developing their academic and sociocultural weaknesses. (p. 379)

This was also the case for COSMOS. As a Math and Science Upward Bound Program, its primary goal entailed strengthening the mathematics and science skills of the students who met the eligibility criteria such as being first-generation college bound, low income, having at least a 2.5 cumulative grade point average in high school, being in 9th or 10th grade at the time of application and showing an interest in math and science. Yet, in the eyes of the participating youth, the program was seen primarily as a gateway into college:

> What I like best about COSMOS is that there are people that really care and that are here to help you out, because obviously, we are low income students, we're gonna be first generation college students, we all have the potential to be something bigger and better, you know, but we just need that extra push, and so all our main staff and even our aides are here to help us and they care about it. [Youth Participant]

Participation was about confidence building and the learning of having a "right for a college education" (Assistant Director) irrespective of one's background. Further, the residence component of the program was particularly powerful in acculturating the youth to an institution they would have not had access to otherwise:

> I hope that through their exposure to our program and too, being on campus, that they learn that they have every right in the world to be here. Because they think with first generation kids, they're not sure they have the right. They know they're smart enough, but they don't know they have the right to be here, so maybe we can show them that. [Assistant Director]

To experience the right to be in college but also in science was crucial. The latter was achieved through involvement in hands-on science activities over sustained periods of time. In the first year, youth pursued a science project given to them while in the second year, the science project evolved from their own interest tied to the scientific theme they explored at that moment – the physics of sports – leading to projects on the physics of skateboarding, soccer, and golfing. In the third year, youth had an opportunity to engage in science at the elbows of scientists. They became members of a science community contributing to projects in biochemistry, ecology, and physics. Through scientific presentations, they shared their learning with their peers, parents, and all program staff at the end of each program year. Throughout the school year, they received some guidance by the staff through monthly school visits. They also received help preparing for college entrance exams, college applications, and in their search for scholarships for college. Clearly, the designated identity of the program was a youth that was an insider to science and that would pursue a career in science (Anna Sfard and Anna Prusak 2005). Interestingly, but maybe not surprisingly, such a designated identity became a handicap for many. Take the example of Brian, who was convinced that the program "helped and molded me into college-bound material," attesting to much self-confidence in "making it" in the system. Yet, after engagement in science in college and failure in biology, he let go of the science part in attempts to stay in college and save face: "I didn't care what it was going to take to stay in school, I was going to do it." While he had dreamt about studying at the Massachusetts Institute of Technology (MIT) "since I was eight years old," and later often referred to a career in engineering or possibly working at the Navy Intelligence Department, he eventually switched major, and dropped out of science altogether, pursuing a triple major in International Business, History, and Construction Management, hoping there would be a job one day in that field. He certainly valued becoming educated and had enjoyed science and had an opportunity to develop a vaster vision of science due to his participation in the program. Yet, in terms of the outcome, the program failed in making him a literal insider to science.

In contrast, Hannah entered the program with a strong interest in science that aligned itself well with the designated identity of COSMOS. In fact, the program made visible to her a means whereby she could combine mathematics and science, her two favorite school subjects, by eventually pursuing a career in engineering. The designated program identity aligned well with who she wanted to become and was becoming. Two years past participation, Hannah proudly shared her college experience with me:

> College has been very kind to me. My grades are great and I ended up landing a full ride at the engineering school. I'm enrolled in a 5-year degree program. At the end of the program I will have a BS in Engineering Physics and a MS in Electrical Engineering. [Email exchange, October 2003]

Hannah often referred to her parents and the manner her mother supported her by taking money out of her retirement fund to pay for school: "[T]hey wanted to see me fulfill what I have always wanted to do." She referred to COSMOS as "awesome" and as having helped her considerably, giving her the social capital needed to make it into college. Further, she received three credits for the algebra course she completed in the last program year. Her high school did not offer any upper-level science or math classes that could have prepared her in terms of the disciplinary knowledge, making such course credit particularly valuable. Later she added: "[I]f it wasn't for COMSOS I don't think I would be in the position I am in right now." When asked about her future, Hannah was unsure, but she certainly wanted to work in her field: "Physics, I might as well use the physics if I have to go through the excruciating pain of learning [it], relativity and quantum mechanics is not all that easy." Later she talked about NASA and how she would possibly move out of state for a job with them. Hannah had clearly appropriated an identity as an insider to science and may be considered the kind of youth such outreach programs aim for and hope to support. Most important, the case underlines clearly that access to other practices also mattered – such as quality school science experiences, family support, and now, access to meaningful and challenging science activities and practices, something that the engineering school could offer.

Such was not the case for Edric, who also entered COSMOS with a strong interest in science and by working at the elbows of scientists in the biochemistry lab appropriated and made his own the designated identity of COSMOS, positioning himself as an insider to science. It made him sign up for a bachelor degree with a major in science at the same University that housed the program. Yet to our surprise, Edric graduated 3 years later with a Bachelor of Arts with a major in communication studies. He described COSMOS as "a once in a lifetime opportunity, and I would not take it for granted," recognizing it as his "ticket" into the college pipeline, given his position as a first-generation Latino immigrant. Working on a drug compound that could be used one day to replace morphine in a research team of COSMOS, he could talk at length about the value he saw in such work: "I'm working with a new drug that, that may make it out into the market one day, that would be cool, if it comes out one day, you know, I worked on that drug, bragging rights, that would be cool." When we talked in his second year in College, Edric was frustrated about the fact that he could not get into more science courses at the University. His focus changed: "I just want to get out quick and start earning money, you've got to pay bills and stuff like that. … I want to do something in the medicine field still, I just don't see myself going for another 12 years after my college, right now, my biggest concern is getting out quick and start earning."

As for many other youth in similar economic positions, the pursuit of a long education became an ongoing economic challenge. Moreover, it made Edric pursue an education in an institution with fewer resources, further challenging his position as an insider to science. His case illustrates in interesting ways how COSMOS offered him with opportunities to appropriate the social capital needed to pursue an education, yet such social capital did not automatically translate into economic capital. The gendered, racial, and class-divided nature of science and higher education played out against Edric. He was not able to use his insider identity to science in transformative ways to persist in science or to break down some of the class-related barriers to science. He argued he could not, as is, persist in science, due to the economic demands and subsequent demands on his time, underlining the manner he lived the contradiction between his lived insider and outsider status. To graduate with a bachelor in the arts, majoring in communication studies was "both an act of self-preservation and an act of defiance" (Calabrese Barton 2007, p. 338), as it has also been described in lived contradictions in school science for marginalized youth (Angela Calabrese Barton and Kimberley Yang 2000). Yet, his case, along with the others, does not point to the failure of University outreach programs with a focus on science, technology, engineering, and mathematics (STEM), in bringing outsiders into science. Instead, they underline well how elusive such a task is as long as the structural features of the system remain unquestioned. As long as the structures that frame marginalized youth's experiences with science are left unquestioned, the reproduction of elite scientists will continue. The gatekeeping devices currently in place will keep most diverse urban youth out, while possibly leaving just enough room for occasional success stories such as Hannah to filter through to ensure, maybe, the unquestioned sustainability of such structures.

Youth-Driven Community Science Programs: Some Examples

Some researchers have started to take seriously the premise that children and youth come into contact with science in a variety of contexts irrespective of who they are and, hence, have a rich history of engaging in and with science in diverse ways over time, yet ways that may fall outside of the borders of science as currently defined. It led to community science programs in which science is co-constructed among the participating members and hence, is defined by the participants' lived experiences, worlds, and histories. An example is the science practice that came to define a group of youth in a homeless shelter, a project initiated by Barton and colleagues (1998, 2003). The mixed feelings about living in a homeless shelter and the need to come to own a space within such a place of contradiction between safety and a highly regulated, structured, and political place, led to a project on pollution in the community. It made the youth explore their neighborhood, eventually turning it into a place they were proud to live in and feel good about. Their negative emotions about living in such a place became the driving force behind their explorations of the science behind pollution and the actions they were ready to take to make an environmentally safer place out of their community, and to come to own a piece of it. Other activities that came to define that program were food experiments. Given the regimented eating schedule at the shelter, many children struggled with hunger at night, making food an important part of their daily struggles and, hence, a potentially interesting bridge into science too. Examples of activities are the edible play dough project and pizza experimentations – activities that took over the agenda at many occasions. In both instances, the youth put science to use in the context of their lived challenges – living in a shelter or often being hungry. As such, the intellectual, the emotional, and the physical constituted the science that emerged.

The pursuit of science fair projects on a question of concern to youth is another form of engagement that gives voice to students as my observations in an after-school science program for "girls only" suggest (Jrene Rahm 2010). One girl described the program as:

> It is about being with my friends, and to work on something I like doing, there is nobody here who says 'you have to do this or that', they let us choose our projects and then it is our responsibility to get them done.

Samira, another participating youth described her engagement in science fair projects:

> The first year, I think I did a project on optical illusions and I remember that there are people who take drugs that are called "hallucinogenic" and they have illusions. The second year, I did a project on rockets and learned that when the rocket takes off into space, there are two parts of the rocket that fall in the water and that are then picked up. And this year, I found out that thanks to fiber optics the voice can be transferred from one phone to another.

Samira participated in the science fair project component of the program for 3 consecutive years and posed questions on topics of interest to her and tied to her everyday experiences. Yet, what made the program special to her was also its psychological accessibility; it was a place she felt safe. As she explained: "I am Muslim and am not really allowed to be in contact with boys, in my religion it is like that." Since the program offered science activities to girls only, her parents did not oppose participation and it became a psychologically and culturally safe place for her to play with an insider identity to science.

That program shares many components with others that have attempted to tap into youth's cultures and histories as a means into science (see Margaret Eisenhart 2008). These examples underline the ways science is co-constructed and the manner interaction patterns behind such work differ drastically from those observed in other settings. The youth's questions drive the curriculum and offer opportunities for them to integrate different ways of knowing science and validate the links they make. Discourse analysis of science in such programs underlines too that youth have much to say about science and "know more about it than they are usually given credit for or allowed to express" (Eisenhart 2008, p. 91). That such is the case comes through also in science video documentaries youth had an opportunity to construct in yet another community science program. Melina Furman and Angela Calabrese Barton (2006) argue that an examination of how youth use their voice in the context of such a project can be particularly revealing for our understanding of youth's participation in vast repertoires of science practices and their scientific literacy development, and the work that goes into solidifying their identity as knowledgeable and capable of science. It suggests that community science programs may be safe spaces to show and act upon an interest in science, whereas in school, such may have to remain hidden so as not to jeopardize ones popularity among peers. Finding ways to deal with such contradictions, two girls in a garden program I studied simply identified themselves as environmental activists; something they argued had nothing to do with science, which they judged as boring anyway. By distancing themselves from science in that manner, they protected themselves yet could be engaged in environmental activism in their free time.

In summary, studies of community science programs that have youth at the center not only offer key insights into the role such contexts play for the development of scientific literacy and identity as an insider to science, but point to the many dimensions that need to be explored if we are to ever understand and in turn support, the making and becoming of youth in science.

Discussion

Scientific literacy development remains problematic for many low- and moderate-income children and youth, and not surprisingly, afterschool, community, and university outreach programs have been solicited to help with the task. It is as if informal science and out-of-school (OST) learning has been discovered as a potential quick fix to an ever-increasing problem of scientific illiteracy in North America. Yet, as my first example underlines well, quality out-of-school science programs, while important, cannot be held responsible for a system that excludes and is driven by an elitist and narrow notion of science and what engagement in and with science entails. I described programs that adhere to broader notions of science and that offer youth with opportunities to become agents of science and their own selves in science. I also discussed community programs that incorporate the concept of student voice, which Melina Furman and Angela Calabrese Barton (2006) take to entail the students' perspectives and, hence, their opinions of problems and potential solutions to making science inclusive of who they are and are becoming. Most importantly, the programs I explored are illustrative of science practices where youth can come to see themselves as "potent actors in their worlds" and develop an agentive sense of self in relation to education, science, and science careers (Glynda Hull 2008, p. xv). In these programs, youth have the opportunity to narrate a place of self in science in relation to who they are and are becoming, as well as in relation to their past and current trajectories within and among the diverse science practices that are and have been accessible to them over time. The descriptions underline well that learning trajectories and identities like engagement with and in science need to be understood as taking on many forms, as being continuously in the making, and as being defined and constituted by participation in vast repertoires of practices. If such were to be accepted, engagement in science outside of school would no longer be silenced next to elite or school science – the science of power. It would make possible a move beyond the dichotomy of "'inside/outside' of school which has fueled the 'culture of power' in science education" and the practice of excluding (Calabrese Barton and Yang 2000, p. 876). Youth's engagement in and with science in programs such as COSMOS or the afterschool science program for girls only described earlier would be understood as assets toward a trajectory in elite institutions. As is, COSMOS youth were shortchanged by the system given their position in society as diverse youth living in poverty and at-risk and, hence, in need of being fixed. Their academic potential and actual contributions to the making of science were spatially marked and recognized and supported in COSMOS but less clearly so beyond that space and time.

Conclusion

> You know, science is just getting out there and learning about the world around us, whether you know its reactions in chemistry or the butterflies outside, you know, the mountains, the ocean, it's everywhere, you can't get away from science. [COSMOS Youth]

As suggested by the quote, becoming an insider to science entails, in the words of Dawn Currie, Kelly Deirdre, and Shauna Pomerantz (2007), the "negotiation of a multitude of competing and contradictory discourses" (p. 381). It translates into a research focus that also needs to explore the diversity of science practices that the youth engage in and in relation to which they continuously redefine themselves. While many COSMOS youth could not realize the designated program identities of becoming scientists, the science they engaged in due to program participation still constituted who they were becoming as adults and the form their scientific literacy took, over time. What they had learned in COSMOS or the science club became interspatially linked with other science practices they engaged in. Their affiliation and engagement with science in COSMOS, the club, and other community programs I touched upon, made accessible to them heterogeneous sets of cultural knowledge that then constituted their future learning trajectories in important ways. Yet, ironically, such forms of engagement in and with science are still too often ignored and rarely considered as assets when marginalized youth attempt to enter the world of science and its pipelines.

Given our lives in an evermore complex global world filled with challenges and contradictions that can only be solved through diverse and challenging collaborative actions, we can no longer afford to lose the voices of youth. As long as we do not move beyond the era of positivist science, and the dominant discourse of physics as the ideal model, and do not make room for competing discourses and positions within science as the ones I described in this chapter, many youth will remain positioned as outsider of science. Gwyneth Hughes (2001) says it well, "science needs reforming, not its students" (p. 288).

This chapter suggests that a reformulation of scientific literacy development as constituted by youth's participation in a vast range of repertoires of cultural practices and official acceptance of those ways of knowing and engaging in science as tools for action in the future would bring to a halt the current disillusionment with science in education. Studies as the ones summarized here can teach us much about what a more inclusive notion of science and science practice may entail. Now it is up to us to listen and in turn challenge the power differentials that keep marginalizing such ways of conceptualizing, engaging, and being in science.

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Chapter 5
Reality Pedagogy and Urban Science Education: Towards a Comprehensive Understanding of the Urban Science Classroom

Christopher Emdin

Problematising Science Education for Urban Students of Colour

Science education is traditionally framed as a field of study that focuses on the teaching and learning of science across the educational spectrum (Cheung and Keeves 1998). It also encompasses all fields of study that are related to the education of students in the sciences (DeBoer 1991; Duschl 1998), Consequently, it has a broad scope and functions to meet the needs of all students in all science classrooms through a variety of means. While this broadly defined definition of science education serves to address the needs of the various constituencies within the field of science education, it does not provide enough focus on the needs of specific populations who have traditionally been marginalised from success in the sciences. In particular, students of colour in urban settings who have been reported to not be as successful in the sciences as their counterparts of other racial and ethnic backgrounds, and in other settings, have not had their particular needs addressed in science education (Norman et al. 2001; Tate 2001). This is not to say that science educators do not discuss the teaching and learning of urban youth of colour in urban setting. In fact, researchers who consider these issues are scattered across the landscape of science education. However, a specific focus on the needs of these students is not a prevalent strand of the research. I argue that this issue persists because of the lack of a concerted effort to specifically address the needs of urban youth of colour in science classrooms. Efforts to specifically address the needs of these populations and other progressive approaches to research and practice are slow to becoming accepted within traditional science education and the preparation of science education researchers (Jablon 2002). I argue that this is neither a reflection of blatant disinterest in the needs of urban

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youth of colour nor a conscious bias against these students. However, it is a reflection of a combination of a deep-seeded disinterest, pre-existent, under-explored and institutional biases, and an inability of the field of science education to evolve quickly enough to meet the needs of a growing and significant component of the constituency in schools.

The Silencing of Urban Youth Voice in Urban Science Education

In accordance with existent approaches to science education, researchers opt to engage in studies that align with the more dominant paradigm of studies which focus on more 'familiar science education topics' that require embedding in multicultural issues in order to be truly effective (Aikenhead 1993). Important approaches to science education – such as constructivism, the nature of science and pedagogical content knowledge – can be ineffective in urban classrooms without a specific focus on the needs of the most marginalised students within urban science classrooms and how they make sense of, or can benefit from, the use of these topics. Compounding the aforementioned issues are challenges such as the historically scattered nature of urban youth attendance in schools (Steward 2008), the impact of larger societal issues such as globalisation and gentrification of urban education (Lipman 2004) and, that within the spaces urban youth of colour inhabit, student voices are not heard and therefore do not inform educators and researchers about the types of approaches to teaching/learning that best serve them (Cook-Sather 2002). The above phenomena point to the fact that students of various ethnic and racial backgrounds across many urban contexts endure a plethora of issues that function to silence them in science classrooms, with science education as a discipline reaffirming this silencing.

This phenomenon (the silencing of the urban students) is often swept under the rug through a focus on broad-based approaches to science education that focus on initiatives that rightfully push for, among other things, an effort to provide all students, across backgrounds, with the same resources (Bybee 1995). The thinking behind this approach is that the equitable distribution of resources and instructional strategies across contexts will allow for some equal focus on the needs of students whether they have traditionally been marginalised from attainment in science or not. The strength in this approach is that it stands as an effort to reverse historical practices that have removed resources from youth of colour because of their societal positioning as not having the ability to be successful in challenging subject areas like the sciences. The weakness in these types of proposals is that this effort becomes ineffective because the provision of equal resources for all students at this point in time in science education necessarily maintains existent achievement gaps and the effects of inequitable practices.

Urban Science Education

The Needs of Urban Youth in an Urbanised World

Urban science education research, which in its true form focuses substantially on the needs of urban students thorough an understanding of their realities both within and outside the classroom, breaks from the traditional paradigm and focuses explicitly on what can be gained from the teaching and learning of science from the urban student's perspective. In efforts to focus on and consider the information for science teaching and learning that comes with this perspective, particular attention must be placed on the societal positioning of marginalised populations across the globe and the negative associations that comes with this labelling.

The current and ever-growing rise of globalisation and urbanisation serve as a charger of sorts for a focus on the experiences of the marginalised in urban settings and the reform of their schools (Lipman 2004). The effects of globalisation on the demographics of urban areas across the world has been described as particularly problematic for researchers in fields such as urban planning and economics, where the sheer numbers of people within urban settings and the creation of new urban settings where they have never before existed, has become overwhelming (MacLeod 2002). In fact, researchers have reported that, in 2009, more than 3.3 billion of the Earth's 6.6 billion people will be urbanised, rising to 5 billion in 2030 (UNFPA 2008).

While this research is often accompanied by how these demographics directly relate to the rise of slums, poverty and violence, I argue that science education is positioned to consider the positive effects of this urbanisation on the concentration of people who have been marginalised from, among other things, the learning of science. For example, immigrant families from certain Latin American countries, who travel to the USA and quickly become a high percentage of an urban neighbourhood, can be viewed as contributors to a lower socio-economic standing of a neighbourhood or can be seen as resources for shaping a more multilingual and inclusive science classroom. Students in a rural context who quickly become classified as urban students because of a sharp spike in population can be perceived as underprepared for using science to meet the job needs of an evolving and more technical society or can be utilised as resources for gaining insight into how science plays a role in shaping students' perceptions of self in an ever-evolving society. In the highly organic and continually changing urban spaces, progressive urban science educators can focus on initiatives that empower a large number of students to be full participants in science more than ever because of the high populations of the marginalised and socio-economically deprived who have become localised to urban areas. Globalisation, and the accompanying urbanisation of certain areas, can then be viewed as strengths that allow more complex and important work in science education.

Science Education in Urban Settings or Urban Science Education

Perceptions of urban students of colour as dangerous, uncivil and disinterested in school (Davis 1995), combined with the fact that youth of colour in these settings have traditionally not done well in science compared to their peers (NCES 2006), has caused urban science education to gain much popularity among certain scholars. While it is not necessarily supported as a field of study in its own right within science education, it is often fetishised and perceived as cutting edge or part of a new wave of research. Consequently, it has caught the attention of many scholars that position themselves as progressive. It also results in the advent of research that has a focus on studies in science education that exploit the recent intrigue in science education within urban contexts and utilise these contexts as a backdrop to their research that could have otherwise been omitted from the study. While a majority of these studies are intellectually sound and contribute to scholarship within the larger science education community, I argue that the continued pursuit of the urban context as backdrop or insignificant component of science education research could diminish the necessary attention to academic work within the discipline that exclusively focuses on a deep interrogation of contexts and the establishment of research that is undertaken to specifically address the needs of urban minoritised youth within urban contexts.

Context here refers not just to physical spaces beyond the classroom, but also to various interrelated phenomena such as cultural traditions, ways of knowing and being, and general sensibilities that are specifically urban. Understanding context in this sense lends to the understanding that ‘scientists and non-scientists benefit by recognizing that attempts at mutual influence, multiple frames of reference, and “objective” information in science communication are not neutral but evaluated with other social influences’ (Weber and Word 2001, p. 487), and that these influences impact on the ways in which conversations between students and teachers occur in the classroom. The interplay between ‘Westernized’ culture of science and the more communal ways of being of students in urban settings become glowingly apparent when research studies that are presented as urban science education do not thoroughly consider the contexts of urban settings. In fact, these studies only serve to affirm the established misconception held among students, teachers and academics that being of colour and urban are different from being able to be successful in school or science.

Moving Towards a Focus on Reality

Science educators who have begun to move beyond the use of the urban context as just a backdrop to their work, have began to uncover aspects of science teaching and learning that directly speak to the urban experience. These scholars have began to focus on sociolinguistic issues and ethnicity (Rodriguez 2003), socio-cultural dynamics within the urban context (Roth et al. in press), developing democracy in urban science classrooms (Basu 2008), and addressing specifically urban issues such as homelessness (Barton 1998), socio-political action (Hodson 1999) and hip-hop culture (Emdin 2009). These studies move beyond *science education in urban contexts* to *urban science education* as a distinct field of study that is particularly focused on context and providing equity to urban students. In these studies, science teaching and learning and other foci of traditional science education studies, such as professional development or science curricula, serve as an adjoining focus to a thorough consideration of context. With this approach, the goal of developing mechanisms for improving science education is so intertwined with addressing the specific needs of urban populations that they cannot be teased out within an academic study. These types of studies consider the nuances of context through an understanding and exploration of the realities of the urban student experience.

Searle (1995) describes the concept of reality as an agreed-upon outlook on or about social life, based on how it is perceived or created by a particular group of people. He argues that reality is essentially based on 'facts relative to a system of values that we hold' (p. 15). Therefore, if urban contexts hold diverse populations who have shared understandings based on their various experiences, these populations can be said to have certain realities. These shared realities provide information about not only the influence of the contexts of urban areas on their experiences in classrooms, but provide information about how students react to the teaching and learning of science.

From Pedagogy of Poverty to Reality Pedagogy

A focus on students' realities in research is directly related to a brand of pedagogy that also considers context and student experiences as the point from which effective teaching begins. I argue that if research and theory are to genuinely impact practice, then a focus on context and student realities within these contexts should match a reality-based pedagogy that it informs and that informs it. Reality pedagogy is an approach to teaching that begins with student realities and functions to utilise the tools derived from an understanding of these realities to teach science. Hodson (1999) provides a fertile ground for reality pedagogy in his questioning of urban schooling and questions such as: Whose view of reality is being promoted? Whose voices are heard? And why? He then ties this line of questioning to realities in urban science classrooms in later work when he states: 'In most classrooms, there is a conscious or unconscious reflection of middle class values and aspirations that serves to promote opportunity for middle class children and to exclude children of ethnic minorities and low socio-economic status, who quickly learn that their voices and cultures are not valued' (p. 790). Therefore, in order to answer these questions in ways that allow the voices of urban youth of a lower socio-economic status answer to the questions that Hodson posed, a move beyond the established approaches to pedagogy in urban settings is necessary.

This established approach to pedagogy found in urban settings is described by Haberman (1991) as a 'pedagogy of poverty' which emphasises certain types of practices which breed a certain reality in the classroom that causes students not to see the science classroom as a space of which they are a part. This type of pedagogy promotes a particular focus on basic skills and factual knowledge in science, provides little to no room for cultural relevance, and foregoes culturally sensitive pedagogy that promotes science language skills (Ladson-Billings 1995; Pomeroy 1994).

Defining Reality Pedagogy

Reality pedagogy acknowledges non-dominant standpoints of students and the nuances of their experiences outside of the classroom and utilises their position as 'other' as the point from which pedagogy is birthed. It considers the process of transitioning from a student's life world to the science classroom as a cross-cultural experience (Aikenhead and Jegede 1999) for which the culture of the student is significant in the classroom. When reality pedagogy is developed, transformative teaching is enacted and, consequently, research in science education within classrooms becomes informed by approaches to instruction that consider new approaches developed specifically for students in particular urban classrooms. Students define what effective instruction is and discuss how it is enacted in the classroom. This approach begins from the point where there is a consideration for what Cobern (1996) describes as the consideration of different cultural contexts that produce different sets of beliefs and realities. Cobern argues that these realities predispose individuals to feel, think and act in particular ways. I argue that an understanding of these realities, or efforts to understand them through research, provide information about what types of activities cause students to feel, think and act in ways that are conducive to learning science or that alienate them from it. When student perspectives on issues, such as ways to engage in certain activities in the classroom, ways to communicate with students, and means for enacting effective instruction are considered, feeling, thought and action that support science are enacted by students.

The goal here is not to change science or re-establish what topics are a part of the curriculum (which might be a necessary goal for some science education researchers), but rather an understanding of how the ways in which the specific science topics in the classroom are being delivered causes urban youth to feel, think or act in ways that are not conducive to their success in the classroom. Through reality pedagogy, the existing classroom reality, which might inhibit students from conceptualising and investigating the natural world, is questioned and a more comprehensive understanding of the inner workings of teaching and learning and their effect on urban youth are addressed. The outcomes of this questioning can be a challenge to what the teacher considers to be science and or science teaching and the distinctive ways in which it is traditionally delivered. However, through this questioning, success, participation and effective teaching and learning are redefined in ways that allow students to feel as if they can attain them.

Enacting Reality Pedagogy

Enacting reality pedagogy requires an understanding of the student's communities and the use of this understanding to positively affect the teaching and learning of science. The goal for the teacher who enacts this pedagogical approach is to immerse himself or herself so deeply in student culture that it becomes second nature to find ways to develop student interest in, and natural affinity for, science. Embarking on the journey towards enacting this pedagogy is an opportunity for science education to bear witness to the realities of those within urban settings.

Bearing witness is connecting to the ways in which individuals are denied full participation in society, as well as being able to identify and make connections with these individuals' experiences, despite the fact that one might not have physically experienced or seen all of the same things (Oliver 2000). Reality pedagogy is teaching based on witnessing and acknowledging that traditional science education and structures both within and beyond the classroom have negatively affected the ability of urban students of various racial, ethnic and cultural backgrounds to connect to science. Therefore, a pedagogical approach that has components both within and outside of the classroom is necessary for connecting urban youth to science.

> In order to meet this challenge [increasing racial, cultural, ethnic diversity among the populations attending urban schools] teachers must acquire the cultural competency for creating productive and inclusive learning environments, building academic capability among all students, and forging solid relationships with students' families and communities… (Murrell 2006, p. 81)

In my work with beginning teachers who work in urban schools, I have been able to guide them towards enacting reality pedagogy by incorporating certain practices into pre-service coursework and guiding them to utilise the information from these activities in the classroom when they begin teaching. While this is not a complete protocol or an outline of what should be the steps taken to enact reality pedagogy, it is a set of steps that I have implemented and found successful in helping teachers to move towards its implementation.

Steps Towards Reality Pedagogy in the Classroom

Teachers can visit student neighbourhoods/physical contexts once a week and communicate with people in neighbourhoods, such as store owners. Teachers can observe and take notes on phenomena in the neighbourhood and work towards using them as examples and analogies that relate to the science curriculum. Teachers can spend time listening, observing and participating in artifacts from student culture (including music, specific types of dialogue and other activities). Also teachers can verify the accuracy or effectiveness of their notes, observations, examples and analogies with students in structured dialogues and discuss how these artifacts can be used in the science classroom with students.

The teacher can deliver the lesson based on studies of notes, observations, examples and analogies discussed with students in structured dialogues. Teachers can videotape the classroom when these artifacts are used as part of the pedagogy as they can invite students into dialogues and uses the videotape of the classroom as a jumping-off point for discussion. (Participants in the dialogue view the videotape of the classroom, identify part of the lesson that needs to be improved and develop plans of action for improving the lesson.) Teachers and students can return to the classroom to implement the plans of action discussed in the dialogues.

A Focus on the Three Cs: Co-generative Dialogues, Co-teaching and Cosmopolitanism

In the steps to enacting reality pedagogy mentioned above, one of the most important steps is the first C (co-generative dialogues). These are the structured dialogues mentioned above that occur among students and their science teacher at least once a week for discussing what goes on in the classroom (Tobin et al. 2003). In groups of four to six students, participants engage in dialogues, sometimes based on video from the classroom, and discuss student perspectives on what is going on in the classroom. Through the enactment of this practice, student realities are investigated and issues that they have with the classroom are allowed to be brought to light and addressed in the classroom.

In conjunction with co-generative dialogues, co-teaching (the second of the three Cs) is a practice that allows both students and teachers to take on the role of teacher. In this process, students and their teacher return to the classroom to implement plans of action from co-generative dialogues. This step fits in with the final step in the in-school rituals listed above. In its enactment, it allows the student to take on responsibilities traditionally reserved for the teacher and allows the teacher to learn about student realities. Furthermore, it allows the student to take on the traditional co-teacher role by assisting the teacher in teaching science. In other words, the implementation of plans of actions from co-generative dialogues necessitates that students who are involved in the dialogues begin to share responsibility for the classroom through co-teaching. The last C (cosmopolitanism) is a philosophical tenet that is evident in the classroom when a co-responsibility for one another and a valuing for each other's realities is part of everyday experiences in the classroom. When cosmopolitanism is enacted, there are multiple co-generative dialogues being enacted, endless instances in which co-teaching with students are in place, and connections between the teacher and students and students with each other are more of the norm than the exception.

Conclusions

The goals of this chapter are to present how urban science education requires a thorough understanding of student realities that go beyond what is available through conventional approaches to science education and to articulate the need to focus on context through a valuing of students' reality. The chapter shows that the combination of a constantly renewed awareness of the role of context in urban science education, a focus on the realities of the urban student experience that is often masked in science education, and a thorough focus on practical steps that can be taken to begin moving teachers towards reality pedagogy provide new approaches to researching and teaching in urban science classrooms. The combination of the approaches to science education, the challenges to the field of study, and the tools for enacting research and pedagogy presented throughout this chapter move science education towards a more comprehensive view of the urban science classroom in the sense that it exposes aspects of the classroom that are not traditionally prominent and guides the field towards new approaches and new discoveries. Focusing on the contexts surrounding the urban science classroom through student realities presents an approach to science education that opens up new ways for understanding what has worked for urban students in science classrooms and what has not, while concurrently allowing teachers and researchers to uncover approaches to improving urban youth experiences in science classrooms that exist, but have not been given an opportunity to work.

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Chapter 6
Learning Science Through Real-World Contexts

Donna King and Stephen M. Ritchie

A significant global challenge for a future dependent on science and technology is to engage students in science programmes that are relevant for the knowledge society. Many current science programmes privilege de-contextualised conceptual learning, often limited by a narrow selection of pedagogies that too often ignore the realities of students' own lives and interests (e.g., Tytler 2007). The context-based approach is an initiative in chemistry education that adopts an alternative rationale for learning experiences for students compared to traditional or conceptually focused programmes. While context-based programmes generally aim to improve student engagement by situating the learning of science in contexts that are meaningful to students, there is a lack of conformity about the meaning of 'context-based'. This chapter begins by reviewing literature relating to context-based approaches to learning, focusing on international trends in curricular development. Following this, outcomes from context-based interventions are examined. These include student interest, attitudes and motivation, as well as perceived relevance and conceptual understanding. Finally, the chapter culminates with a proposed meaning for context-based approaches that might be adopted internationally.

Use of Context in Science Education

The context-based movement finds its place among a large number of developments such as project-based learning (PBL) or inquiry-based science education as well as science–technology–society (STS) approaches that attempt to make the learning of science more meaningful for students. These curricular developments generally strive to achieve an in-depth understanding of a few key ideas instead of the conventional coverage of scientific content, and attempt to enhance learning, improve the

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relevance of the science being taught and the engagement of students, as well as increase personal satisfaction for participating students. Both PBL and STS approaches have been reviewed extensively, the former by David Boud and Grahame Feletti (1998), and the latter by Judith Bennett, Frod Lubben, Sylora Hogarth (2007). While they share common features with the context-based approach, they will not be part of this review.

John Gilbert (2006, p. 960) defines the term 'context' with reference to its Latin derivatives: the verb 'contexere' means 'to weave together', and the noun 'contextus' expresses 'coherence', 'connection' and/or 'relationship'. Thus, the function of context is to describe such circumstances that give meaning to words, phrases, and sentences. In other words, a context should provide a coherent structural meaning for something new that is set within a broader perspective. These descriptions are consistent with the function of the use of contexts (p. 960) in chemical education: students should be able to provide meaning to the learning of chemistry; they should experience their learning as relevant to some aspect of their lives and be able to construct coherent 'mental maps' of the subject (Gilbert 2006).

However, there appears to be comparatively little debate in the literature about the meanings of context-based approaches as applied to science education. Elizabeth Whitelegg and Malcolm Parry (1999) suggest that context-based learning could have several meanings:

> [A]t its broadest it means the social and cultural environment in which the student, teacher and institution are situated. A narrower view of context focuses on a specific application of a theory, for example, application of physics theory for the purposes of illumination and reinforcement. (p. 68)

Yet, applications of science to the real-world features prominently in discussions on context-based teaching and, therefore, will be further explored.

An important part of learning in science is to link contrived classroom activities to events in the real world, usually with reference to a resource (e.g., artefact). The teacher and students can best utilise this resource if the topic is taught in context; that is, it is taught through addressing relevant societal issues or phenomena (Sutman and Bruce 1992). In other words, an authentic context for learning science can facilitate the development of desirable scientific practices (Ritchie and Rigano 1996). When students use ideas in familiar situations and consolidate relationships between science concepts and these experiences, their confidence with the topic can be enhanced.

While real-world application appears to be inherent in the use of context-based approaches in science education, there are different views about how this should be applied in the classroom (e.g., King 2007). Despite these differences, context-based programmes show promise in effecting favourable learning outcomes.

Outcomes from International Studies on Context-Based Approaches

Five international context-based chemistry programmes that were highlighted by Albert Pilot and Astrid Bulte (2006) are included in this review. The five programmes are: Chemistry in Context in the USA (American Chemical Society [ACS] (2001), Salters in the UK (University of York Science Education Group [UYSEG] 2000), Industrial Science in Israel (Hofstein and Kesner 2006), Chemie im Kontext in Germany (Parchmann et al. 2006) and Chemistry in Practice in The Netherlands (Bulte et al. 2006). We have also incorporated in the review, research that was conducted in the 1970s and 1980s for physics that provides further evidence of positive outcomes for context-based learning (i.e., PLON, Physics Curriculum Development Project, Eijekelhof and Kortland 1988). Common themes emerged from the literature on the six projects which fall into three key areas: relevance, interest and deeper understanding.

Relevance

Context-based education helps students see and appreciate more clearly links between the science they studied and their everyday lives (e.g., Hofstein et al. 2000). The Industrial Chemistry project in Israel, focused on how learning industrial chemistry case studies affected students' perceptions of their classroom learning environment. Three groups of Grade 12 high school students majoring in chemistry were selected for the study. Two of the groups (Groups 1 and 2) were exposed to an industrial chemistry case study whereas the third group of students, a control group, were not. The analysis revealed that Group 1 students outperformed the other two groups of students regarding their perceptions of the relevance of their chemistry studies. In addition, they achieved higher awareness of the social implications of their chemistry studies, for example, they found that their chemistry studies better prepared them to become future citizens and informed them about occupational possibilities (Hofstein et al. 2000).

A second study that investigated the relevance to students' lives of a context-based curriculum occurred during the evaluation of The PLON project. This project began in 1973 as a physics curriculum development project for general secondary education in The Netherlands. Contexts such as Working with Water, Living in Air and Energy in our Homes structured the PLON curriculum. One particular study of the project investigated the reality-centredness and activity-centredness of the curriculum materials. Activity-centredness referred to activity learning where the students performed a learning task in an independent and autonomous way rather than being guided and controlled by the teacher. Reality-centredness referred to the extent to which the subject of physics was presented explicitly in relation to everyday life and to students' out-of-school experiences (Wierstra and Wubbels 1992, 1994). The two groups of students that were selected for the study included a PLON group of students and a control group. The control group of students were from classrooms taught with a more traditional textbook. Student perceptions of the classroom environment (reality- and activity-centredness) were measured by a classroom environment survey administered after a mechanics lesson from the context of Traffic. Statistical analysis of the results revealed that the PLON students experienced the lessons of the context-based unit Traffic as more reality- and activity-centred than students in the traditional course (Wierstra and Wubbels 1994). Furthermore, other evaluation studies of the PLON project confirmed this result and showed that in most cases reality-centredness also promoted student appreciation of physics lessons (Wierstra 1990).

Interest/Attitude/Motivation

Students' interests in and enjoyment of their science lessons are generally increased when they engage in context-based courses (e.g., Ramsden 1992, 1994, 1997). Research from three international context-based programmes: Salters, ChemConnections and Chemie im Kontext revealed that most students had a positive experience in context-based courses.

The key principle that underpins the Salters approach is that the ideas and concepts selected and the contexts within which they are studied, should enhance the appreciation of students of how science contributes to their lives (Ramsden 1997). The main concepts are introduced in a drip-feed manner throughout the course and once introduced are constantly reinforced in different ways (Barber 2000, p. 11). The course makes use of a wide range of learning strategies; for example, group discussion, problem-solving exercise, role play and creative writing (Ramsden 1992).

Mary Barber (2000) compared students' learning in a traditional syllabus (i.e., with a strong emphasis on chemical facts, theory and concepts) with the Salters context-based course. She found that the Salters course was perceived as more interesting and varied (Barber 2000), however, the less able students in the Salters course found it difficult coping with the lack of routine and the applied nature of the questions (Barber 2000).

Judith Ramsden (1997) compared the performance of students on a range of diagnostic instruments following both a context-based approach (Salters) and a more traditional approach to high-school chemistry. The study showed there was little difference in levels of understanding, but there appeared to be some benefits associated with a context-based approach in terms of stimulating students' interests in science.

Joshua Gutwill-Wise (2001) investigated the impact of context-based learning in introductory chemistry courses, in particular ChemConnections modular materials, in two universities – a small university and a large university. The modular approach was very similar to the context-based approach since it involved a change in the content and pedagogy of the chemistry classroom. The shift in content emphasised chemistry as real-life problems such as building a better automobile air-bag system, investigating global warming, and understanding atmospheric ozone depletion. Modular classrooms consisted of new pedagogical approaches such as group work, discussion and the use of multimedia. Students in the context-based class at the small university showed more positive attitudes than their traditional counterparts, but the reverse was found at the larger university. When the course was taught for a second time at the larger university using only modules that had undergone rigorous editing, the surveys found these students more positive than students from the previous study. Therefore, some of the problems were resolved in subsequent courses.

Chemie im Kontext (ChiK) is a context-based project in Germany that is modelled on the ideas of the Salters courses. Since 2002, outcomes from ChiK have been investigated in several research projects (Parchmann et al. 2006). For example, a comparison between the motivation to learn chemistry of ChiK students and students learning within a conventional curriculum showed that the motivation of students following a conventional curriculum decreased significantly compared with the ChiK group (Parchmann et al. 2006). Furthermore, after 2 years of the project more than 60% of the ChiK students at the end of Grade 10 and Grade 11 stated that they wanted to choose chemistry in the upper secondary level. Ilka Parchmann et al. also found that the application of knowledge, the perceived personal relevance of chemistry and the influence of the teacher were important for the positive development of students' interests in chemistry.

Deeper Understanding

The earliest research study that investigated the relative merits of a context-based programme on students' conceptual understanding was conducted in the 1980s on the Dutch Physics programme PLON. The research revealed that PLON students did not achieve better results on traditional high school examination questions compared to students studying the traditional physics course (Wierstra 1984). However, Harrie Eijekelhof and Piet Lijnse (1988) argued that traditional education was fully aimed at these examinations and hence the conclusion could be made that PLON students were at least not harmed in their preparation for further studies through a context-based approach. Furthermore, Harrie Eijekelhof and Piet Lijnse (1988) rationalised that differences between curricula are often reflected first in the learning environment, and it is only later and in moderated form that these changes show in student-learning outcomes.

The ChemCom course was developed for upper secondary students in response to a need for a course which prepared students for effective resolution of science-related issues in the real world through a knowledge and interest in chemistry (Sutman and Bruce 1992). The results of the testing programme that assessed both chemistry learned and applications of chemistry, indicated that students completing the entire year-long ChemCom course significantly outperformed students completing more traditional college prep chemistry on test items designed by ChemCom writers (Sutman and Bruce 1992). Also, a second study found that minority students learned more when using ChemCom compared with a more traditional approach (Winther and Volk 1994).

Two similar studies comparing the understanding of chemical ideas between context-based (Salters) chemistry students and traditional chemistry students occurred in England. Firstly, Vanessa Barker and Robin Millar (2000) undertook a large-scale, comparative, longitudinal study of 400 upper secondary level students at 36 schools in England following A Level chemistry courses, including Salters Advanced Chemistry. The study employed a series of diagnostic questions on key areas of chemical understanding, administered at three points over an 18-month period, and showed comparable levels of understanding across all courses. In particular, they found that students who experienced a gradual introduction and revisiting of ideas in different contexts at several points during the Salters course appeared to develop better understanding of these ideas than students following more conventional courses (Barker and Millar 2000). Secondly, interesting data came from a study by Mary Barber (2000), who used a range of performance indicators to compare predicted and actual grades in Advanced level Chemistry examinations for Salters Advanced Chemistry with a group studying a more conventional course. Her study indicated that there was no particular disadvantage or advantage to students in either course in terms of the final examination grade they achieved. Although students took different examination papers, all examinations had to meet externally imposed standards, so the study provided additional evidence that the learning by students on context-based courses is comparable with that of students on more conventional courses (Bennett and Lubben 2006).

In another comparative study of Chemie im Kontext (ChiK), Gabriele Lange and Ilka Parchmann (2003) found slightly better results (significant, but low effect) for ChiK classes, compared to other classes who were taught a traditional unit in acids and bases (Lange and Parchmann 2003).

Recent Developments in Australia

In Australia there is a small body of research on context-based teaching from two states, Victoria and Queensland. In Victoria, this approach has been adopted in the Victorian Certificate of Education (VCE) syllabuses for physics and chemistry with some claims to success. Unlike Victoria, Queensland does not have external examinations; hence, teachers are able to offer more flexible opportunities for the introduction and success of a context-based approach in the teaching of chemistry and physics.

Context-based teaching in a new physics course for senior high school students was implemented in Victoria in the early 1990s (Hart 1997). Research conducted on the success of this course confirmed the prior research on international context-based approaches that many students perceived greater relevance of physics to real life and expressed an increase in motivation (Vignouli et al. 2002).

In Queensland, the context-based chemistry syllabus has been on trial in schools since 2002. Despite personal feelings of anxiety (Beasley and Butler 2002), some teachers who had been using this approach reported an increase in student motivation and enjoyment. However, there was a clear lack of independent research to support these statements (Lucas 2002). Research on both the VCE physics course and the Queensland context-based chemistry course revealed some new findings that have not been discussed in the literature so far.

Research by Vincent Vignouli et al. (2002) and John Wilkinson (1999) showed teachers were concerned that teaching physics in context resulted in the inability of students to transfer their learning and apply concepts in situations outside the context in which they were learned. Consequently, they feared that students would be unable to appreciate the general applicability of the physics principles. Unsurprisingly, concerns about transfer are not unique to a context-based course. Traditional physics courses are still implicitly based in an abstract, idealised context, and assume that the student will be able to transfer their learning to a range of real-world situations. Furthermore, past research has demonstrated that students do not generally transfer their learning (e.g., Pfundt and Duit 1997).

These findings contrast with a more recent study (King et al. 2008) in Queensland where a student who had completed 1 year of a traditional chemistry course and then repeated the year in a context-based chemistry course, demonstrated connections between concepts and contexts. In an interview after the completion of both courses, she made a purposeful connection between a chemical concept and the context of water quality. On this occasion, the student explicitly abstracted principles from the solubility rule that all nitrates are soluble, learnt in the traditional chemistry course, to the presence of insoluble materials in water, when she explained an experiment she had completed in the context-based unit on water quality.

The programme of research into context-based approaches to chemistry has been continued by the authors in a further study. A context-based unit on water quality structured the teaching and learning of a study in a year 11 chemistry classroom in a private boys' school in Queensland. In this study, the teacher designed a sequence of lessons where the real-life application (context) was central to the teaching and content was primarily taught in response to the students' need to know. However, the implemented pedagogy of the teachers changed during the unit due to her perceived constraints of time to complete the planned curriculum and opportunity for students to demonstrate the level of conceptual understanding she had anticipated. Even though the teacher was committed to implementing pedagogical change that prioritised student–student interactions over teacher-led content coverage, she was unable to maintain this for the whole duration of the unit. The study found that the paradigm shift or 180 degree change in student and teacher behaviour (Beasley and Butler 2002, p. 2) that was the intention of the new context-based syllabus, was too extreme even for a reflective, competent and willing chemistry teacher.

Further research from the same study revealed insights into how students learn in a context-based chemistry classroom. We used the metaphor of fluid transitions, which originated from the work by King Beach (2003) on collateral transitions, to refer to instances where the students' discourse moved back and forth between the chemistry concepts learnt in the classroom and the real-world context. The study investigated the structures that afforded students agency for fluid transitions to occur.

Structures are enacted by what Giddens calls 'knowledgeable' human agents (i.e. people who know what they are doing and how they do it), and agents act by putting into practice their necessarily structured knowledge (Sewell 1992). So structures make no sense apart from agency: what salient structure is depends on the participants in a situation (the students), their past experiences and the rules or schemas that have been developed in the classroom. Thus, because agency and structure are co-dependent and mutually presupposing concepts, they exist in a dialectical relationship represented as agency|structure.

The study found that students exercised their agency differentially depending on the resources to which they had access. In other words, successful learning in a context-based classroom was dependent on students accessing resources such as content knowledge, prior academic achievement in science and sound English literacy skills to achieve fluid transitions between sanctioned chemistry concepts and real-world contexts. Furthermore, the study showed that fluid transitions were realised in the written activities and student–student interactions where students made connections between concepts and contexts (King 2008).

The Search for a Unified Meaning of Context

Context-based approaches have attempted to make the meaning of science concepts more relevant to students through the application of canonical knowledge to the real world. We would argue that context-based teaching is more than transfer or application of concepts to the real world. Rather, context-based teaching embodies a need-to-know principle: the context must legitimise the learning of concepts from the students' perspectives, which is more likely to make their learning intrinsically meaningful. Following on from more recent research, the question then arises: How can classrooms afford students the opportunity for fluid transitions?

Pierre Bourdieu (1990) viewed the world as 'socially produced', in and by 'a collective work of construction of social reality' (Grenfell 2007, p. 54). He employed his own scientific (sociological) concepts such as a *field* to explain the dynamic relationships between structures and the people who occupy them. A field is 'a structured social space based on the objective relations formed between those who occupy it, and hence the configuration of positions they hold' (Grenfell 2007, p. 55). This notion of field enables the study of related social spaces at the macro (e.g. education), meso (e.g. school) and micro (e.g. classroom) levels – fields within fields (Grenfell 2007).

The recent study conducted in a year 11 chemistry classroom in Queensland (King 2008) revealed that fluid transitions occurred when the students used the discourse of science to explain water pollution in the local creek. That is, in their classroom conversations, the students were moving to and fro between the canonical science and the water quality of the local creek. Fluid transitions occurred when the students' transactions overlapped two or more fields simultaneously; that is, the field of the local community and their problem with the pollution in the local creek, and the classroom field. Even though the students did not appreciate fully that the creek was situated in the broader context/field of the local community, their classroom conversations showed evidence of merging discourses from each field. This perspective is helpful in identifying further opportunities to enhance fluid transitions.

A study by Angela Calabrese Barton et al. (2007) found that the connections between science and student worlds were not just there ready to be revealed in the classroom. On the contrary, they were successfully created when they took students into the field of their local community to learn about the science of fresh produce. The students actively found connections by engaging in conversations with community representatives (in this case a farmer and local produce manager) so that the community issues became integrated into the students' everyday lives. Calabrese Barton et al. (2007) also found that the students were not only seeing scientific topics in their everyday lives but also using science to make choices and influence other people's actions.

In relation to the study of the water quality of a local creek, further opportunities for enhancing fluid transitions might be realised by visiting the sites from which the water samples were taken; that is, the local yacht club, the sewage treatment plant, as well as observing the community use of the creek over a period of time, talking to local residents and visiting the local council office to discuss water treatment practices and storm water drainage systems. After the students have been immersed fully in the real-world field, it is possible that the toing and froing or fluid transitions may be replaced with a blending of the canonical science and the real-world context where the distinction between the two is indefinite. We define this blending of discourse as resonance.

Fluid transitions between the sanctioned science content of school curriculum and student worlds can be realised when students actively engage in fields that contextualise inquiry and give purpose for learning. Furthermore, if teachers employ pedagogical approaches that encourage diffusion through the porous boundaries of the fields, they open up possibilities for the merging of students' everyday literacies with the canonical science.

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Chapter 7
Collaborative Research Models for Transforming Teaching and Learning Experiences

Rowhea Elmesky

> *As I reflect back on my first few months of teaching at CHS, I recall some fleeting moments that gave me the satisfaction of being a teacher. Sadly, many days …I came home and wondered: "Am I a failure as a teacher?" … The greatest challenge that I faced was to be accepted by them as their teacher. I wanted my students to know and understand that I was there to help them and not to punish them with detentions and suspensions. … Their academic level was well below grade level, and the word "science" was enough to repel them from doing any productive work in the classroom. In my entire life, I always tried to do the "right" things, but here I was sitting in a high school classroom without knowing how to do anything right. I was frustrated, but I promised myself that I would work to make things better. (p. 49)*

Apparent in this quote from an autobiographical reflection in Anita Abraham's dissertation, satisfaction and feelings of worth as a science teacher are connected to the type of classroom community that forms and to the nature of the interrelationships arising among students and with their teacher (Abraham 2007). For many teachers in urban schools, it is a daily struggle to teach science. They often experience frustration or failure in building classroom communities where they are able to successfully connect with or be "accepted by" their students. In fact, Anita's experiences of dissatisfaction and frustration as a new science teacher in an inner city school are indicative of the experiences of many new (and experienced) teachers in urban schools.

In studies by researchers such as Richard Ingersoll (2000), analyses of the Schools and Staffing Survey (SASS) and the Teacher Follow-up Survey (TFS) reveal that the retention of teachers, and particularly mathematics and science teachers, is directly linked to factors which include dissatisfaction. In fact, 40% of mathematics and science teachers who depart from the field cite their dissatisfaction as stemming from sources that cause them to feel disempowered. Specifically, two of

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the major causes of displeasure for teachers who decide to eventually leave the profession are student discipline problems and perceptions of minimal student motivation. I suggest that these teachers, similar to Anita, may feel stripped of *agency*. According to William Sewell (1992), agency infers that one has the power or capability to shape the social relations in which one is embedded, "which in turn implies the ability to transform those social relations to some degree" (p. 20). Teachers wish to experience a sense of empowerment within the classroom and specifically in their interactions with students, thus, pointing to the fact that addressing the challenges of teacher retention and satisfaction requires attention to classroom dynamics, and specifically to the strengthening of social relationships with students.

This chapter shares a narrative of one immigrant science teacher's (Anita Abraham) experiences while working in a comprehensive neighborhood school with students from different social, cultural and economical backgrounds than herself. Further, the chapter provides images of how classroom experiences can become better understood from multiple vantage points when collaborative research is incorporated into the classroom, during and outside of class time, as occurred during the critical ethnographic study that Anita was conducting, with me, under an NSF-funded grant. The grant invoked a model of collaborative research (utilizing a "research with" rather than "research on" methodology), and teams were created at every school site to consist of two teacher-researchers from each participating urban school, at least two student-researchers from each focal class, and university researchers such as myself. Specifically, the chapter emphasizes how introducing researcher roles into the classroom helps to strengthen weak relationships between teacher and students, encourages the development of new teaching and learning roles, and improves the critical consciousness of both teacher and students.

Anita's Story

Although she held a bachelor's degree in Chemical Engineering from India, Anita decided to go back to school to become a teacher when she immigrated to the USA. Even before she finished student teaching, she was offered her first teaching job at City High School (CHS), a large Northeastern urban school with a nearly 99% African-American population, the majority of whom were from the surrounding low socioeconomic neighborhoods. CHS lacked human and material resources; with its concrete walls and heavy metal double doors, it looked more like a correctional school than a high school. During her first year, teaching at CHS was overwhelming. Anita found that many CHS students had lost hope and interest in school as a means to acquiring a viable education. Many students did not have access to resources like pens or paper. In general, students did not express interest in doing class work, and questioned the relevance of Anita's teaching by asking questions such as "Why do I need to learn this?" or "Where am I going to use it?" For the majority of the time, Anita felt that her primary job as a teacher was to work on classroom management issues rather than to teach. In an autobiographical reflective piece, she wrote: "I had no clue how to respond or what to do, and my inability to control the class and influence their attitudes haunted me day and night; I went to bed late thinking about the unpleasant events that I had experienced in the classroom." Anita felt that the students did not respect or acknowledge her as their teacher, and instead, were considering her as an outsider or someone who did not belong in their community because of her ethnicity and accent. Questions such as "Why are you here?" or "Why is everybody coming to our country?" made Anita feel disempowered. She wondered how to respond or what to do. The students' statements seemed to communicate that she was an intruder, making her first year of teaching painful and disappointing.

Even beyond that first year of teaching, the social, cultural, racial, and economic divide between Anita and her students was complex and daunting. As stated in the quote opening the chapter, Anita believed that "her greatest challenge was to be accepted by them as their teacher." Year after year, she tried an array of "quick fix" strategies, yet eventually she realized that she needed to develop meaningful relationships with the students. Becoming a teacher-researcher helped pave such a pathway, and Anita's case provides support for advocating the use of collaborative research models in science classrooms.

Collaborative Research in the Science Classroom

> Anita: As a science teacher at City High School, I had seen university researchers walking down the halls, in classrooms and also in the principal's office. Most of the teachers were suspicious about the university researchers. They tried to avoid them, were apprehensive about being interviewed by them, and afraid that they might accidentally say something that might put them in "trouble." In those days, I wasn't sure what the ongoing research was about, and I didn't make any effort to know either. Things started to change when our vice principal, a former science department head, asked me to join the Master's in Chemistry Education (MCE) program offered at the same nearby university. At the same time, Dr. Kenneth Tobin, the main university researcher from the Graduate School of Education, asked me if I would be interested in joining the research group already working at City High School. He further explained to me that, as a part of the research team, university researchers would have access to my classroom and I also would be participating in the research as a teacher-researcher. As a regular classroom teacher, I didn't consider myself a researcher and didn't know what qualifications were expected for a researcher. Moreover I wasn't comfortable letting a university researcher into my classroom. I was worried that, if things went out of control, those events would become the focus of their research findings. When I shared this information with one of my coworkers, Ms. Cloud, a 30-year veteran teacher, her reactions were negative, mainly because in her opinion educational researchers always concluded their findings without any input from the classroom teacher or students. However, I anticipated that my situation would be different because I would act as a teacher-researcher and my students would also become a part of the research team as student-researchers. Although I was still slightly apprehensive, I agreed to be a part of the research team, excited that my voice and my students' voices would also be heard during the research process.

These reflections shared by Anita, following the completion of the study, illuminate the mixture of emotion arising when teachers are asked to incorporate *research* into the classroom context. The remainder of the chapter describes some aspects of the research process in which Anita, student-researchers, and I collaborated during 2002 in her 11th grade Chemistry class and supplementary laboratory at City High School.

Critical Collaborative Research as a Tool for Daily Classroom Change

Urban schools, such as City High School where Anita taught, are marked by inequalities – visible in school staffing, funding, courses offered, and the resources available. The schools are often oppressive to students who are labeled as "resistant" or "unmotivated" and classrooms become grounds for conflict, disconnect, and struggle. However, critical ethnographic methodology and methods are tools for shifting classroom dynamics from "control over" to "collaboration with." That is, when participatory critique is encouraged, transformation in the classroom occurs and schooling can become a less oppressive experience and more rewarding for both the students and their teachers.

When Angela Calabrese Barton (2001) discusses critical ethnography, she describes the research process as a "dialectical theory- and practice-building process in which practice and research shape each other in an endless cycle" (p. 907). Thus, critical ethnography calls for identifying the problems and asks for transformation by connecting theory and practice. This dialectical relationship between practice, theory, and research triggers local transformation of the structure by providing tools for all participants to act in new ways as the findings from the research constantly inform participants of their practices and vice versa. Moreover, critical ethnographic methods increase the agency of the participants through methods that are inclusive of all of the stakeholders involved. Collaboration is key and necessitates that teachers and students take on researcher roles that allow them to draw strength from the research findings. Thus, both the research process and the associated findings serve as catalysts for growth and transformation.

Students as Researchers

Kenneth Tobin (2006) has conducted educational research that involves students as researchers and found that this type of model "provides a way to obtain their [the students'] perspectives on what is salient in terms of school, teaching, learning, and myriad other issues" (p. 27). That is, when student-researchers are included in salient ways in research studies, teachers are afforded greater opportunity to understand their perspectives on what is occurring in the school or neighborhood fields and, importantly, "why." Through the new role of "researcher," they significantly contribute to identifying patterns of coherence (as well as contradictions) within their classrooms, in relation to the teaching and learning they experience.

In Anita's classroom study, student-researchers engaged in activities such as the review and analysis of videotapes, interviewing each other and fellow classmates, transcribing such interviews, writing reflective journal entries, and developing video ethnographies that captured salient aspects of their lifeworlds outside of school. Weekly, the researchers ate lunch together, during which time they watched videotapes from class time and from within the laboratory. They were asked to identify video vignettes of salient events that were taking place, and these video vignettes then became focal points for discussion. In addition, a selection of video vignettes was shared with students who were participants within a captured video clip, in order to obtain their perspectives and to preserve and privilege their voices.

When Students Speak

With the introduction of a research design in Anita's classroom that employed students as researchers, the students quickly learned that their perspectives were valued and that it was acceptable to be critical of classroom practices. For example, in the following entry from one student-researcher's (Deidre's) journal, she highlighted a major issue present in schools like CHS where there is a culture of distrust of students in laboratory settings.

> I think Mrs Abraham should trust us and plus the burner, she gotta go to group to group, lightning it and its gonna take a long time and we wanna do our lab real quick and by her keep goin to group to group she just need to give us like some matches or a lighter so we can [light the] burner our own? Burner is easy to use. (2/02)

These types of reflections were useful in helping Anita to identify how her teaching practices afforded and truncated students' performance within the laboratory setting in a school where deficit perspectives of the students were the norm. In fact, for years, most students at CHS did not receive opportunities to participate in a science laboratory setting and, specifically, Biology students had been prevented from performing dissections due to the teachers and administration's fear that they would harm each other with scalpel blades. Accordingly, although some teachers like Anita eventually decided to incorporate a lab section into their science classes, there was still a tendency to enact control tactics that truncated student agency. Therefore, laboratory equipment like the Bunsen burner could only be lit by Anita, and this was not received well by students who found themselves waiting on one teacher during the tight slot of time designated for laboratory completion. Through the avenue of research, students like Deidre were able to bring to the surface how such teaching practices could be experienced as inefficient ("she gotta go to group to group") and as disrespectful of their abilities ("burner is easy to use"). Moreover, Deidre was able to represent student interests in having access to a greater range of resources; she was also able to provide concrete suggestions of how the students could experience greater autonomy ("she just need to give us like some matches or a lighter").

Contradictions are a normal part of social realms and to be expected within classroom cultures. Research designs that privilege multiple voices encourage the study of such contradictions rather than the search for patterns of coherence alone. In Anita's classroom, the involvement of multiple student-researchers allowed for various perspectives to emerge. For instance, while Deidre was quick to point out that the students in her class were quite capable (e.g., of lighting a Bunsen burner), another student-researcher (Maria) held a different view. Since the majority of the students in the class lacked previous experience in a science laboratory setting, Maria felt that Anita's assistance was necessary and perhaps even insufficient to meet all of the students' needs. In a conversation with me, she expressed:

> This is our first time for doing something. This is our first time being in the lab. It is our first time all this stuff. It is the first time. But I think she can get more help somewhere else too. She needs to find some more help. (2/02)

Maria's remarks and associated suggestions communicate frustration with schooling structures that have limited her and her peers' modes of participation in science. In the previous science class that Maria and her peers had completed at CHS, the curriculum had consisted of bookwork and lacked any laboratory component. Hence, when the students were in the chemistry laboratory, it was the first time for most of them and there were constant requests for Anita's assistance. She continuously circled the classroom throughout the duration of the laboratory activity, moving from group to group. The demands became strenuous for Anita and a source of negative emotion for both her and the students. Maria noted this in another research meeting:

> She [Anita] teaches but she still needs to be a little more patient with us also. … I think our group was asking for something. She was doing something else and she got like real mad like "I WILL BE THERE IN ONE SECOND!" And I understand that you [Anita] are only one person but we need help also.

Through the student-researchers' perspectives, it is evident that Anita's decision to simply add a laboratory component to her chemistry class did not magically rectify the years of inequitable science learning environments that students like Deidre and Maria had been experiencing. Instead, Anita needed opportunities to consider what resources afforded her students to experience success. Such considerations are fostered through incorporating a research worldview into the classroom where students (i.e., student-researchers) can take a proactive role to support their learning. While it is natural that the students may initially focus mainly on recognizing aspects of the environment that are unfavorable and engage in a process of sharing their frustrations, they will also come to simultaneously recognize teaching practices that foster success, respect, and autonomy. These occurred in Anita's classroom, as the student-researchers evaluated their classroom experiences. For example, although Deidre had been quick to point out that Anita did not allow the students to light the Bunsen burner, she recognized that Anita promoted student autonomy in other ways. For example, Deidre spoke about Anita's practice of encouraging the students to select their own laboratory groups – contrary to other teachers at CHS, stating:

> When we are in the laboratory [in Anita's classroom] and we have to pick who we are in the group with, and you work with people you are already familiar with – some teachers just put you with anybody. If you don't like that person and you are not familiar with that person, you are not going to work because you don't know anything about them. So [in Anita's classroom] you work with your friends and like we have the lab [Rate of Reaction], and we had to mix the chemicals, look at the color change, and time it for one second or two second. It was fun.

Students like Deidre viewed this opportunity for group self-selection as beneficial on multiple levels. Evident in her comments, Deidre recognized that working with familiar peers assisted in the process of carrying out experiments smoothly and in an enjoyable manner ("it was fun"). She also pointed out that rapport and comfort level with one's peers assisted in the completion of lab requirements such as the mixing of reactants, timing the experiment, and recording observations.

In fact, over the course of the semester, video data of the lab showed how the students often took responsibility for their own and each other's practices in the lab. That is, students kept an eye on their group members and on other groups to make sure that they were following procedures correctly. They often provided information by answering questions, sharing techniques, talking through the process and modeling for each other. For example, during a laboratory activity on physical and chemical changes, one group wanted to finish the activity quickly and decided to put the baking powder directly into the vinegar without first wrapping the powder inside a paper towel, as the procedure required them to do. However, this did not go unnoticed by a member in a different group who reacted quickly, by shouting, "Stevenson you wrong! Don't take it out! You wrong." Such interactions indicate that the students were acting with independence and as resources for each other within the laboratory, illustrating a spirit of collective responsibility.

Thus, throughout the research process, students had the opportunity to become more conscious of how their peers were functioning as science learners and to recognize shifts in their peers' practices and identities. That is, the student-researchers seemed to develop insights into what was needed to become successful science learners. In a written entry that was recorded in response to watching videotapes of the students in the chemistry laboratory, another student-researcher, Sasin, wrote:

> I think that the labs are the best part of this chemistry class. We have fun with it. I think we get a better explanation by seeing and doing these labs instead of a lecture. … I think we have grown as little scientist[s]. We look more familiar within videos with the equipment. Everyone seems to enjoy the lab. We all like to work in groups.

On a different occasion, as the student-researchers watched some video footage of their chemistry laboratory, they observed and discussed different students' practices and related aspects of the learning environment. For example, while watching a videotape of the students engaged in the Flame Test Laboratory Activity, Maria provided understandings regarding one student's engagement in the classroom. She commented:

> But at 11:07 [AM] we seem like we all were writing down our observation and getting along well. Look at Earl. Earl the type of person that doesn't do any work. He the one that copy and stuff like that. But he not dumb! Earl ain't dumb! He smart he just don't wanna do it … He don't wanna seem like he smart.

Earl was considered to be a troublesome student by many of his teachers, including Anita. During classroom instruction, instead of paying attention and writing notes, he usually put his head down. However, during the laboratory component of Anita's class, Earl began engaging in different practices as a science learner, and this attracted Maria's attention while viewing the video footage. Maria recognized a shift in his practices from someone who "doesn't do any work" and "copy and stuff like that" to someone who was writing down scientific observations and "getting along well." Her summative perspective (i.e., "He don't wanna seem like he smart") was insightful and catalytic. Anita became interested in understanding him better, for example, making efforts to learn more about his home life and experiences in other classrooms. Through her researcher role, Maria helped Anita to focus upon a student whom she had previously somewhat ignored. Thus, I argue, incorporating a collaborative research model into the science classroom assists in deeply interrogating how it may become a space where all students are central and have the opportunity to associate positive emotions and respect with the doing of science.

Sharing Responsibility for Success

> I learned a lot from research. We sit in groups and talk about class an[d] stuff. [Before] I never thought about the other kids and how they feel. I learned how Ms. A [Anita] cares about us. She taught us to help other people in class. I get good grades. Class is just a big group of helpers for everybody.

This chapter does not intend to set up an argument for linear, causal relationships between research and improved social relationships in the classroom; however, I do maintain that collaborative research models introduce dynamic and transformative structures into the classroom that encourage the building of a caring community where shared responsibility is key ("just a big group of helpers for everybody"). Structures, as discussed by Sewell in his article on agency, can be both material resources as well as virtual ones like rules, ideology and schema. For example, evident in Nisha's journal entry above, in Anita's class, becoming involved in research encouraged schema that valued nontraditional teaching and learning roles – where students take responsibility for their own and their peers' learning and where the teacher is someone who genuinely "cares." That is, collaborating in the doing of research encouraged the emergence of a community where students began to think about one another's perspectives ("how they feel"). The students were also able to see Anita as someone who was concerned about their well-being. Moreover, the introduction of research into the classroom helped to create spaces for authentic conversation, for instance, through the use of resources like group "talk." In a school where the students are silenced on a regular basis, the opportunity to *speak* is essential to promoting positive emotional energy in the classroom. In fact, the students in Anita's classroom were quick to share their experiences with research with other teachers. Maria related: "We told Ms Morris [the English teacher] about the research in your [Anita's] class and how we talk about what we like and what we don't and all. She liked it. She said that she might try it."

Reflection in Isolation No More

Many times, teachers make sincere efforts to engage in successful practices and to regularly reflect upon their teaching. As stated by Anita: "Everyday I tried to spend a couple of minutes reflecting on my actions, and at times asking the following question to myself – if I were a student, would I want me as a teacher?" However, arguably, when reflection occurs in an isolated context where the teacher is alone in developing her perceptions, it is difficult to identify and determine why particular practices are successful or not in promoting a positive classroom environment.

There is, however, much to be learned from students' contributions as researchers. The student-researchers' perspectives provide important dimensions for better understanding the classroom than would have been achieved if Anita reflected alone. The students provided important information about how responsibility and respect are aligned, helping Anita to recognize a wide spectrum of student perceptions of her actions; for example, her "helpful" practice of lighting Bunsen burners communicated distrust to some students, and for others, she was not be perceived as being "helpful" enough. She also was able to learn that an unpopular teaching practice (at CHS) of allowing students to work with "your friends" could help students generate positive feelings about science as an enjoyable subject area. The student-researchers additionally helped Anita to perceive the generation of positive emotional energy as central to encouraging a positive atmosphere for learning, where students can grow as "little scientist[s]."

School and classroom structures can be transformed to afford the learning of students in the classroom. Sonya Martin (2004) posits that "only by *collectively* [emphasis added] seeking to expose and examine the structures associated with the process of teaching and learning can contradictions be resolved to afford greater agency for all classroom participants" (p. 203). I suggest that teachers should jointly and regularly reflect with students on classroom practices, and collaborative research models pave out a space for hearing the students' voices. In the case of Anita, working with coresearchers enabled her to become more aware of how her practices were being interpreted and shaping the emotional status of the classroom. Although educational research findings are intended to improve teaching and learning in a classroom, the reality is that traditional research dynamics do not afford the immediate participants of a study with opportunities to reap the benefits; rather the implications of the research findings are for future classrooms. A research "with" methodology empowers students and teachers during the research process. That is, the model of critical research discussed in this chapter introduces a view where research is utilized as a tool that is immediately effective and designed to encourage a sense of empowerment. In this manner, teams of university teacher- and student-researchers become integrated and natural parts of a classroom routine where the learning environment is characterized by an openness to examining practices and taking responsibility for one's own actions.

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Chapter 8
Science Learning in Urban Elementary School Classrooms: Liberatory Education and Issues of Access, Participation and Achievement

Maria Varelas, Justine M. Kane, Eli Tucker-Raymond, and Christine C. Pappas

Paulo Freire, in his book *Pedagogy of Hope* (1992/1994), recounting part of his life and his work, wrote that it was important for him to 'connect recollections, recognise facts, deeds, and gestures, fuse pieces of knowledge, solder moments, *re*-cognize in order to *cognize*, to know, better' (p. 11) to form his ideas, understandings and practice. We believe that this is what needs to happen at two levels in science education: (a) in classrooms, as children engage with and attempt to learn science–figure out what it is, who does science, in what ways, and for what reasons, as well as what, how and why they study it themselves, including whether they can see themselves becoming scientists; and (b) in science education research, as we theorise and analyse data from school classrooms in attempts to learn about teaching and learning of science, especially of children of colour in urban classrooms who are often cheated of just opportunities for science education.

In this chapter, we 'fuse pieces of knowledge' published in major journals of science education (*Cultural Studies of Science Education*, *Journal of Research in Science Teaching*, *Research in Science Education*, and *Science Education*) and of educational research in general (*American Educational Research Journal*, Anthropology *and Education Quarterly*, *Cognition and Instruction*, *Curriculum Inquiry*, *Educational Action Research*, *Harvard Educational Review*, *Journal of Early Childhood Literacy*, *Journal of the Learning Sciences*, *Linguistics and*

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Education, *Mind, Culture, and Activity*, and *Urban Education*) about the science learning of students of colour in urban elementary school classrooms in the USA. These students might be in ethnically homogeneous classrooms, or could be a significant part of racially diverse and ethnically diverse classrooms. We focus only on studies conducted in US classrooms because minority status and context matter in achievement, learning, identity development and engagement (Ogbu and Simons 1998). Furthermore, we focus on the last decade (1998–2008), as there was not much research in science education with students of colour before this time. In fact, in our literature review, we noticed an exponential increase in the number of studies as the decade unfolded, with the majority of the studies appearing in the last 2–3 years. Additionally, we 'solder moments' from our own Integrated Science-Literacy Enactments (ISLE) research programme that has been ongoing for several years now and in which we try to understand the urban classroom as a space for thinking, sharing and challenging, as we explore sciencing (i.e. science in the making) and its products. Here, along with references to published ISLE studies, we also share a few vignettes that have not been published elsewhere, exploring the orchestration of primary grade classroom communities and children's multi-modal engagement with each other, their teacher, materials and science ideas.

Like William Tate (2001), we consider science education as a civil rights issue. That is, children in low-income families, who are members of ethno-linguistic and racial groups that have faced discrimination in various forms, need to have similar opportunities to those that Jean Anyon's (1981) 'executive' class has enjoyed. Such opportunities embrace various important dimensions of the pedagogy of hope, including access, participation and achievement (Freire 1992/1994). However, as Lynne Bryan and Mary Atwater (2002) have documented, many teachers of urban classrooms see their students as less capable, leading to lower expectations, even if their performance is equivalent to students from higher socio-economic backgrounds. Many believe that their students lack motivation and self-control, and failure is inevitable for some low-income students. Being 'fair' meant treating everyone 'the same', ignoring differences and, thus, failing to recognise not only that some children are privileged while others are disadvantaged, but also that children's personal and cultural resources are often aligned with science in complex ways. For example, Josiane Hudicourt-Barnes (2003) challenged claims that Haitian children are non-verbal and unable to actively engage in science classrooms by showing that these children were able to employ the Haitian cultural practice of *bay odyans*, a form of discourse that is similar to scientific inquiry.

Discourses and Identity

In *Pedagogy of the Oppressed* (1970/1990), Paulo Freire juxtaposed the 'banking concept of education' – a prevalent form of education in which students are receptacles, waiting for knowledge to be deposited in their heads – to 'liberatory education'. Practising liberatory education requires a multifaceted approach. Topics must be relevant to children's lives. Children should engage in interesting, hands-on explorations that motivate them. Connections should be built with their own experiences. But, also, teachers need to approach such inquiries in a way that gives children a voice and a role to play in their classrooms, communities and beyond. It is not so much what the activity looks like or what it is to others, but what it is to the children in the classrooms, how they find a place in it, and how science becomes a possibility for them, not as a career down the road, but as a way of thinking about the world right now.

Enacting liberatory education is challenging. Even teachers who attempt to go against the grain by implementing culturally relevant practice often fall victim to creating participant structures that characterise a banking approach. For example, the study by Terry Patchen and Anne Cox-Petersen (2008) focused on two teachers, of Latino/a and African American students in a 4th grade and 2nd/3rd multi-age class in South Central Los Angeles, whose intent to teach in a culturally relevant way was not realised because their practice turned out not to 'match the weight of their culturally connected theory' (p. 1007). Questions shared in these classrooms showed evidence of rebalancing authority between teacher and students and encouraging student interaction. However, shifts in authority were manifested on conceptual, but not structural, levels. Moreover, although the teachers recognised students' prior knowledge, this knowledge 'was not necessarily extended in ways that… [would] actually exhibit a more profound valuing for what students bring into the classroom' (p. 1004), and connections that students were making between their personal experiences and scientific concepts were not determined by themselves but by their teachers. Recognising and considering power relationships was missing, albeit needed. Everyday and science Discourses – with capital 'D' to signify Gee's (1996) recognisable coordinations of people, places, objects and ways of speaking, listening, writing, reading, valuing, feeling and believing – were not integrated.

Bridging together everyday and science Discourses in ways that are helpful to student learning has been identified as an important way of serving students of colour. Elizabeth Moje and her colleagues (2001), who studied a 7th grade class of Latinos/as from the Dominican Republic, argued that constructing 'third spaces' for science and literacy is not about privileging everyday Discourses, but building on them to help students to make connections between everyday and science languages so that one does not only inform the other, but merge to construct a new kind of discourse and knowledge. However, this is not easy to achieve and the teacher is a critical factor. Moreover, conflicts can exist between home and school science Discourses in project-based approaches. At times, although words are spoken in two languages (Spanish and English), teacher and students 'talk across each other because the words that they use not only have technical meanings but are also embedded in particular Discourses and funds of knowledge' (p. 478), thus leading to 'bumpy classroom discourse' (Varelas and Pineda 1999).

Research on urban classrooms has contributed to our knowledge base about how students' identities are formed in science classrooms and the role that they play in scientific discourses and practices. Using a discursive identity perspective – identity construction based on an individual's use of language – Bryan Brown (2004) and his colleagues have designed an instructional approach (Directed Discourse Approach to Science Instruction [DDASI]) to help students of colour to bridge home and school science Discourses and learn science. DDASI uses 'double talk', pairing vernacular and academic modes of talk so that there are multiple access points of the same idea. In a study of a 5th grade class of African American students, Bryan Brown and Eliza Spang (2008) found that double talk can blend genres and has the 'potential to position [students] as particular type of persons…[by serving] as a public marker of [a student's] knowledge of scientific terms…[thus using] language as a learning tool' (pp. 725 and 730). The teacher's use of double talk was eventually reflected in the students' talk as they made this hybrid model part of their communication. As students were immersed in scientific language, they came to accept it as part of their own being. "Students were given a vision of science that was connected to their collective experience [and, thus, the classroom was transformed into] a linguistic environment where scientific discursive identities were the norm' (p. 731).

For an urban classroom to become a place where liberatory education is enacted requires a delicate dialectic. Individual children need to maintain their distinct voices (Wertsch 1998), but the class also needs to produce common language, understandings and modes of engagement. Individual children put forth different perspectives as they try to shape what is to be learned and constructed, which is what Wertsch calls 'alterity'. However, within the many differences, particular unities emerge – unities in meaning making, ways of doing, interacting, performing and producing that lead to making a class like an 'ensemble', a piece performed by multiple players who play their own parts, but produce one whole together. Wertsch calls this sharing of perspectives 'intersubjectivity'. It is the construct of what he called 'dialogic intersubjectivity' that allows us to balance voice and unity, and difference and a communal direction, and that might be the result of Mikhail Bakhtin's (1981) interplay of two forces – a centrifugal force that pushes away from a central point and out in various directions, and a centripetal force that pulls toward a central point – resulting in access to learning science.

As an example from our work, in a 3rd grade Latino/a classroom, children and their teacher 'pushed and pulled' in various ways to construct a position related to the humane treatment of animals (Arsenault et al. 2007). In the context of dialogic read-alouds of information books, children made intertextual connections sharing content of their own choosing and meaning which has been shown to be a productive learning approach (Pappas et al. 2003). Lorenzo, Samuel and eventually Antonia shared stories in which they or others had trapped fireflies in containers with no holes, or had killed bugs. As the teacher kept being concerned about the loss of life, first Christopher and Sally were able to pick up on her cues and position animals humanely, and then Andres offered that he had buried a chipmunk that he had found, and this drew positive feedback from the teacher. The humane treatment of animals had become an identity marker valued by the teacher that was eventually picked up by many students. Although, later on in the unit, Samuel again shared another story about killing lightning bugs, many children were offering stories that positioned them as 'nice to the animals', but also let them engage with science ideas related to what animals need for living, life cycles and animal interactions. The children's individual life experiences and everyday Discourses shaped the science Discourse that they collectively constructed in the classroom with their teacher, and the science Discourse shaped their ways of thinking of their own experiences.

Analysing classroom interactions in a 5th grade African American low-income public school in a major urban centre, and particularly focusing on three boys, Bryan Brown and his colleagues (2005) found that the types of people whom these three boys were perceived to be influenced their learning. They argue that ‘the values imbued in the interpretation of a student’s response may have lasting effects of students’ willingness to engage in the taken-for-granted scientific discourse and, ultimately, on how the student may be viewed as scientifically literate or not’ (p. 798).

Transformations of identity are influenced by various factors. Edna Tan and Angela Barton (2008a) focusing on one Latina, Melanie, among 20 girls whom they had studied in New York City middle schools, analysed how girls’ identities are transformed over time, and how instrumental teachers are in their development. Melanie changed from a ‘girl who passes’ to ‘shy presenter’ to ‘valuable group member’ to ‘Jane Goodall the primatologist’ to ‘confident presenter’ to ‘science talker, science storyteller’ to ‘member of core group of supportive friends’ and to ‘helpful co-leader of group’. Melanie was allowed to use her opinions and stories to gain access to the classroom discourse and teacher–student interactions fostered her participation in and learning of science.

Stacy Olitsky (2006) also conducted a series of identity studies with four female 8th grade students (three Black, one biracial) that show that student constructions of self as science learners are connected to successful learning in science. Students need to see themselves as members of the science community – as scientists – and thus teachers need to position themselves as learners so that they can create affordances for students to be part of the construction of knowledge (Olitsky 2007a). If teachers are ‘stage-front’ experts, students feel less involved and see science as ‘hard’. If teachers position themselves as learners and allow students ‘backstage’ to see the process of learning, students perceive themselves as part of the science community. It is not simply the relevancy of the content to students’ lives that draws them into science; rather, it is the feeling of group membership (Olitsky 2007b). As small groups do not always allow all students to participate equally, whole-class interactions are also needed so the teacher can be sure that all students are included.

Dialogic intersubjectivity was also evident in 3rd graders’ own narratives about their student identities (Kane 2009; Kane et al. 2007). For example, in our own ISLE research programme, Lawrence, an African American 3rd grader, thought of himself as having a distinct voice among his classmates because he noticed details and asked questions that others did not. He shared during an interview: ‘Like that boiling thing [hot pot for boiling water]. How do the boil thing make the ice melt? That’s what I ask and other students didn’t think of that’. He also thought that his teacher believed that he was unique and spoke differently to him than to others. From her tone of voice, he inferred that she was excited about something he had said, and he felt proud when told that she ‘never heard any student say that before’ or ‘she never saw another student do that before [referring to his artwork]’. He also saw himself as having an artistic voice, an ability to draw cartoons and write stories, which were activities that he had learned and had participated in at home. Nevertheless, Lawrence and his classmates developed similar views about scientists. Like several of his classmates, Lawrence saw himself as a scientist when he wanted 'to know what will happen' and he could 'experiment with stuff', and he saw scientists as people who learned a lot and could 'see things they've never seen before and keep doing it [seeing things anew]' to see if it will happen again and again. He felt frustrated in school because his classmates knew the answers more quickly than he did and rejected his sometimes unconventional scientific reasoning, and, thus, he preferred to work with Kenny who was a willing and patient listener.

Other recent research by Angela Barton and her colleagues (2008) shows how identity relates to the multifaceted ways of being in a classroom. Considering all 20 case studies of girls in failing New York City public schools (mentioned above), they identified three practices in which these girls engaged: creating signature science artefacts, playing with identity, and negotiating roles through strategic participation. 'Girls were playful with identities in ways that allowed them to transform their narrative authority they have through their lived experiences, into epistemic authority in the classroom' (p. 89). Girls showed that they cared about others, the quality of their work, art, music, movement and verve – funds of knowledge that African American girls and Latinas bring to the classroom, which allow them to take up knowledge resources and identities in new ways. This finding is consistent with Varelas and her colleagues' (2002) study which showed how the rap songs and plays that 6th grade African American students wrote served as sites where their own familiar, social and emotional meanings interconnected with the scientific disciplinary knowledge that they were trying to develop.

Achievement, Engagement and What Counts as Science

One of the commonly heard complaints about our knowledge base regarding classroom learning and engagement in urban classrooms is that achievement in learning scientific ideas has not been considered and/or studied. This is definitely changing. Eileen Parsons (2008), in a study of 23 African American middle school students, found higher student achievement in contexts that incorporated Black Cultural Ethos (BCE) (Boykin 1986; Nobles 1980) than those that did not. BCE includes sociality (playful behaviour by students), time as social phenomenon, verve (intensity and variability, multifaceted activities, patterned movement), movement (musically expressive) and participatory-interactive structure to classroom responses. Similarly, two 6th grade girls in a failing school in New York City authored a place in science (Tan and Barton 2008b) exercising agency by creating their own rules and thus securing a space for participation. 'Authoring acts [such as composing a song or making a puppet]…offered girls opportunities to engage with science content at a deeper level and also to open up a third space for their classmates' (p. 69). Thus, the study supported a strong connection between knowledge construction, learning, identity and science. This connection, however, is quite complex. Sherry Southerland and her colleagues (2005), studying a 3rd grade classroom of African American students, found that academic status influenced meaning making during group work but not in a straightforward fashion. Higher-status students spoke more often, and weaker students were more likely to be marginalised. When academic status was equal, it was rhetorical moves, such as assertive or aggressive utterances, that determined the flow and exchange of ideas, rather than empirical validity of explanation that might be related to African Americans' talk that 'emphasizes visibility and agency of the speaker, and places a premium on rhetorical moves and the affective dimension of talk' (p. 1056).

Furthermore, in the context of a project-based approach in which contextualising is an important principle, Ann Rivet and Joe Krajcik (2008) studied whether contextualising affects learning of scientific ideas. In a study of six students in two 8th grade urban, mostly low-income African American classrooms during a 10-week physics unit, they found a significant positive correlation between these students' contextualising score (determined from classroom observations throughout the unit) and their learning score (assessed through performance on individual instruments and one group artefact [group concept maps]). Although positive learning outcomes were seen, the authors noted that this study cannot shed light on whether contextualising during project-based instruction 'supports learning by providing a cognitive framework onto which students can connect or "anchor" ideas [or]…as a vehicle to motivate and engage students with the learning task' (p. 96).

Also, Okhee Lee and her colleagues (2006), in a 2-year study of 28 3rd and 4th grade students from seven classrooms in the Southeastern USA with predominantly Hispanic students and about 25% English language learners, found that children possess the necessary abilities to engage in inquiry when they are provided with supportive learning environments and explicit instruction to become aware of what inquiry involves. Moreover, using particular ways to scaffold student discussions, Leslie Herrenkohl and her colleagues (1999) have shown similar positive achievement in two classes, one of which was a 5th grade class with a majority of African American students in a Northwest urban school. Once again, the teacher's negotiation and guidance of roles that students assumed in small-group inquiry and when reporting their findings to the whole class were invaluable for student learning and constructing of scientific explanations in sinking/floating investigations. This is echoed in another study with middle-school children in Los Angeles, where Noel Enyedy and Jennifer Goldberg (2004) found that, although two teachers were implementing the same new environmental science programme at their school, the students performed differently on post-tests assessing curriculum concepts. The students who performed better were with a teacher who acted as a co-inquirer with her students by integrating activities and stressing genuine inquiry. The other teacher took on an authoritarian stance with students in activities that were undertaken in isolation and emphasised students closely following instructions.

Investigating a predominately Latino/a (with some African Americans) 8th grade class, Barbara Hug and her colleagues (2005) found that the quality and complexity of questions for investigation that students posed within a project-based science unit on communicable diseases varied, but that students did ask questions that addressed appropriate content (were worthwhile) and had relevance to their lives (were meaningful). Furthermore, although they rarely used scientific language, they were able to articulate and ask about complex scientific concepts. However, students had difficulty following procedures accurately and did not often do careful data collection or observation note taking, implying that students needed help to design and complete complex investigations and get into depth. In contrast, this was not the case in a study with 1st and 2nd grade students in which Susan Kirch (2007) found that 'young students engage in productive argumentation when pursuing open-ended investigations. Students can identify relevant evidence and use evidence to answer questions' (p. 802). Students showed skepticism expressed through questioning and demonstrated complex inquiry skills reflecting a scientific ethos. Again, such understandings developed because the teacher modelled for the students how to be skeptical and ask for evidence, and keyed in on the specific dimensions on which she wanted students to focus. The teacher's critical role in enabling students to reach depth and academic success is also supported by Southerland and colleagues' (2005) study, which showed that the teacher's presence was needed for students to have conceptual discussions.

Moreover, conceptual and linguistic components are intertwined in science learning and we need to understand how this affects students' struggles to succeed academically. Bryan Brown and Kihyun Ryoo (2008), in their study of 5th graders in a predominately Latino/a school in Oakland (California), explored the effect of separating conceptual and linguistic components of science instruction on student learning using the DDASI approach with web-based software they designed for teaching photosynthesis. An experimental class, that was a member of the e-Learning™ community and used the Internet regularly as an instructional tool, was taught by separating content from language – basic concepts were developed without scientific language. A control group was taught with an aggregate approach – concepts were introduced in both everyday and scientific languages simultaneously, and then development of concepts continued in scientific language. Brown and Ryoo found that the experimental group showed significantly greater learning gains between pre-tests and post-tests across various measures, including open-ended questions. Thus, it seems that 'content first yields greater conceptual understanding as expressed in everyday language as well as improved ability to understand and use scientific language' (p. 550).

Entangled with the issue of achievement is what it means to do science, what counts as science and the role that hybridity plays in achievement. As Kris Gutierrez and her colleagues (1999) showed, 'local knowledge', personal experience and narrative offered to a 2nd/3rd grade class opportunities to develop important understandings. Different ways of expressing scientific ideas leads to hybridity, which can become a learning resource. As we have also shown in our work with young 1st and 2nd grade children in urban classrooms (Varelas and Pappas 2006), hybridity of narrative and scientific language that emerged in the context of intertextuality – 'an act of discourse, and an act of mind' (p. 251) – provided a scaffold for children and teachers and eventually led to 'more conventional, public, scientific genres' (p. 252). Furthermore, Warren and her colleagues (2001) illustrated how the 'embodied imagining' (p. 543) in which a 5th grade Latino English language learner engaged when he was studying ants – imagining being an ant himself – offered him a valuable tool for thinking scientifically. Students' ideas and approaches can provide anchoring positions from which to build scientific knowledge. This is clearly a different position than the one that highlights and blames lack of academic success on the mismatch between students' and scientific ways of thinking. It is a position that foregrounds that scientific sense making encompasses a variety of resources, 'including practices of argumentation, the generative power of everyday experience, and the role of informal language in meaning making' (Warren et al. 2001, p. 532), as well as affect, feeling and humour (Varelas et al. 2002).

For such resources to be put to use, divergent talk should be allowed and encouraged so that students can test and explore their ideas and beliefs (Hudicourt-Barnes 2003). When teachers encourage overlapping talk and side conversations and enact dialogic teaching, students find their teacher 'fun', where fun means belonging. As Joanne Larson and Lynn Gatto (2004) argue, dialogic teaching means freedom, power and the feeling that students count as learners in ways that they do not usually experience in school. We also have evidence from the work of Patricia Baquedano-López and her colleagues (2005) that 'breaches' (i.e. places where normal classroom routines are interrupted) can be very productive sites of creation of new knowledge where home and school Discourses can be successfully merged. These breaches allow for teacher improvisation in which students' comments on everyday Discourses, such as 'sometimes uh a long time ago black people used to say solid like this [a raised fist]' (p. 11) in referring to strong friendships, become anchors for talking about properties of solids. In a similar way, we (Varelas et al. 2008) have shown that the use of 'ambiguous objects' in a sorting activity in which students classify them into solids, liquids and gases provide them with 'opportunities to debate, argue, think, and explore' (p. 90). Thus, such research encourages us to trust students' sense making and give them opportunities to engage with science in ways that go beyond constrained views of scientific inquiry and schooling.

To trust students also implies that teachers need to be able to listen to them and hear what they say, especially when they try to express emergent understandings in their everyday language. Ideas that, on the surface, may seem wrong, illogical or scientifically non-canonical can contain worthwhile and 'wonderful ideas', as Eleanor Duckworth (1987) wrote decades ago, or can indicate a deep quest for understanding, which is a genuine scientific practice. In our latest ongoing work in high-poverty schools that educate almost exclusively students of colour, we have found some extraordinary meaning making by young children. In a 1st grade classroom of predominantly African American children, students had to sort an array of solids onto three paper plates – rigid, flexible and smooth. They worked in pairs and were reporting to the whole class about how they sorted their objects as their teacher recorded their classifications on chart paper. Antoine and Keandre were the fourth pair to report and had put a piece of plastic tubing on the rigid plate, which was different from everybody else's so far. Antoine explained, 'If you fill [the tube] in it won't be any room', and kept repeating the same idea after several requests by the teacher to elaborate what he meant by filling it in. Because the class was quite antsy, the teacher asked everybody else to move onto their second way of sorting their materials so that she could talk more with Antoine and Keandre. After reassuring them that they should not change their way of sorting the tube and that they had an interesting idea that she wanted to understand, the teacher asked them to explain again. Antoine mumbled the same idea, but was gesturing that he was filling the tube with something. What Antoine was saying is that, if the tube gets filled in with something, it cannot bend and so it is rigid. Eventually he pointed to Keandre and said: 'Keandre put it in the rigid'. Keandre took the tube in his hand and holding it vertically, he put his fingers around the tube and attempted to squeeze it while saying 'see it's not flexible'. The teacher acknowledged that the tube could not be easily bent in that way and said that 'it's rigid because it cannot be bent that much'. But, then, Keandre turned the tube horizontally and pushed the two ends together as if he was attempting to make a circle, and the tube bent quite easily. Keandre said that it was flexible that way. Eventually Antoine and Keandre came up with the idea that the tube was both flexible and rigid and, therefore, put the two plates next to each other and the tube in between. This is indeed a powerful example of thinking and sense making. What is also important to note is the 'otherness' in Antoine's thinking. Antoine had made sense of Keandre's idea of putting the tube in the rigid section in a different way from the one that Keandre shared. What is important is that Keandre's sorting gave both boys opportunities to engage with the definition of rigidity and flexibility and to think through quite complex ideas. Although simplistically it would seem impossible for something to be categorised as flexible *and* rigid at the same time (two antonyms as teachers would say), the two boys' scientific thinking proved to be sophisticated and meaningful.

Furthermore, this and many other examples found in the literature cited in this chapter foreground the idea that voice is not individually owned and does not express the individual self but, rather, is filled with social content (Bakhtin 1981), thus encapsulating shared meanings that are enacted and modified in the dialogic spaces of the present. Leora Cruddas's (2007) term of 'engaged voices' captures better than 'student voice' the collectivity of thinking and being within an intertextual, highly provisional discursive space where students construct and negotiate social meanings.

Epilogue

We end by recapping the main research findings that we have on classroom learning of students of colour in urban elementary schools in the USA in the last decade. This research was mostly based on qualitative, interpretive methods, but also includes a couple of studies that used quantitative analyses and only one that used an experimental design. This scholarship, which seems to have picked up in the last few years, provides evidence of the thinking, doing, languaging, acting, behaving, feeling and being, which together define learning, that African American and Latino/a students can achieve if given productive opportunities. We know that these students do and can engage with scientific ideas. We know that bridging everyday and science Discourses matters in their engagement and achievement. We know that students' struggles with scientific language can interfere with their achievement and, thus, using approaches in which students can experience success with ideas is critical. Such approaches include: emphasising conceptual understanding and content first before delving into the rigour of scientific language; valuing hybridity and extending what it means to do science; and possibilities for allowing, recognising and nurturing students' ways of making meaning of the world around them.

We know that identity construction and development matters, and that it is associated not only with improved access and participation in science, but also with increased articulation of scientific ideas. We know that the teacher matters immensely, along with the curricular materials available in the classroom to give students access to and success in learning science. We know that power takes different forms in the classroom (discursive, ideological, symbolic and material) and needs to be redistributed and rebalanced so that low-income students of colour can experience and enjoy learning like their White, more affluent counterparts. All the research reviewed in this chapter seems to point to Freire's call for 'the invention of unity in diversity. The very quest for this oneness in difference, the struggle for it as a process, in and of itself is the beginning of a creation of multiculturality…[which] calls for a certain educational practice…it calls for new ethics, founded on respect for differences' (1992/1994, p. 137). Moreover, this research supports approaches that take advantage of differences and use them for creating spaces that not only respect or allow for differences, but also build on them.

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Part II
Learning and Conceptual Change

Chapter 9
How Can Conceptual Change Contribute to Theory and Practice in Science Education?

Reinders Duit and David F. Treagust

Theoretical Developments in Conceptual Change

Conceptual change is not solely of interest to science educators. As noted in Stella Vosniadou's (2008) *International Handbook of Research on Conceptual Change*, whilst science disciplines are the dominant conceptual area for studies in conceptual change, this focus can be found in subject areas such as medicine and health as well as the philosophy and history of science. As is evident in many of the chapters in Vosniadou (2008), because any discussion of conceptual change needs to include the nature of conceptions, many of the chapter authors begin by defining the terms used in the discussion. The notion of what is a conception that could change is an area of current interest as evidenced by the debate between researchers in science education and social science about the nature and interpretation of findings seen as conceptual change (Tobin 2008).

Our position is that conceptions can be regarded as the learner's internal representations constructed from the external representations of entities constructed by other people such as teachers, textbook authors or software designers (Glynn and Duit 1995). From a conceptual change learning perspective, learners need to be able to use different representations of entities to make sense of difficult concepts. For

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example, learning always involves some ways of representing the information learned and science teachers use different representational techniques such as speech, written text and gestures in the classroom to communicate ideas to students. Representations are ways to communicate ideas or concepts by presenting them either externally – taking the form of spoken language (verbal), written symbols (textual), pictures, physical objects or a combination of these forms – or internally when thinking about these ideas. These internal representations are often referred to as mental models and are the essential elements in some researchers' arguments about conceptual change (Treagust and Duit 2008a, b) but not necessarily of other researchers (Roth et al. 2008).

A recurring theme of research findings over the past three decades, as evidenced in many of the chapters in Sandra Abell and Norm Lederman (2007) and Stella Vosniadou (2008), is that students come to science classes with pre-instructional conceptions and ideas about the phenomena and concepts to be learned that are not in harmony with science views. Furthermore, these conceptions and ideas are firmly held and are often resistant to change. Whilst studies of students' learning in science that primarily involve conceptions of the content level continue, investigations of students' conceptions at meta-levels (namely, conceptions of the nature of science and views of learning, as well as characteristics of the learners) also have been given considerable attention in the past two decades (Duit 2009).

Research on the role of students' pre-instructional conceptions in learning science that developed in the 1970s draws primarily on the theoretical perspectives of Ausubel and Piaget. The 1980s saw the growth of studies into the development of students' pre-instructional conceptions towards the intended science concepts in conceptual change approaches. Over the past three decades, research on students' conceptions and conceptual change has been embedded in various theoretical frames with epistemological, ontological and affective orientations (Duit and Treagust 2003; Taber 2006; Vosniadou et al. 2008). A landmark paper by Paul Pintrich et al. (1993) argued that, up to that time, researchers of conceptual change had initially taken on an overly rational approach. Further, certain limitations of the constructivist ideas of the 1980s and early 1990s led to their merger with social constructivist and social cultural orientations that resulted in recommendations to employ multiple perspectives in order to adequately address the complex process of learning (Duit and Treagust 2003; Treagust and Duit 2008a; Tyson et al. 1997).

Amongst the theoretical positions described in Vosniadou (2008), aspects of epistemological and ontological challenges occur in many chapters. During the past decades, several researchers have developed theoretical positions that encompass some but not all of these challenges. Examples include framework theories/synthetic models (Vosniadou et al. 2008), hierarchical ontological categories (Chi 2008), intentional conceptual change (Sinatra and Pintrich 2003) and a multidimensional perspective (Duit and Treagust 2003). Within each of these frameworks, there are three essential aspects of conceptual change learning related to epistemology, ontology and affective/social/learner characteristics. We discuss each of these in turn.

An Epistemological Perspective of Conceptual Change

The classical conceptual change approach (Posner et al. 1982) involved the teacher making students' alternative conceptions explicit prior to designing a teaching approach consisting of ideas that do not fit students' existing conceptions and thereby promoting dissatisfaction. A new framework was then introduced based on formal science that might better explain the anomaly. However, it became obvious that students' conceptual progress towards understanding and learning science concepts and principles after instruction frequently turned out to be still limited because the students were not necessarily dissatisfied with their own conceptions and so the better explanations were not considered. Much research continues in this vein. However, students' conceptions tend not to be completely extinguished and replaced by the science view (Duit and Treagust 1998), but undergo a 'peripheral conceptual change' (Chinn and Brewer 1993) in that parts of the initial idea merge with parts of the new idea to form some sort of synthetic model (Vosniadou and Brewer 1992).

Kenneth Strike and George Posner (1985, pp. 216–217) expanded the conceptual ecology metaphor to include anomalies, analogies and metaphors, exemplars and images, past experiences, epistemological commitments, metaphysical beliefs and knowledge in other fields. Subsequently, many researchers have examined students' conceptual change using explanatory models (Clement 2008) and analogies (Treagust et al. 1996), though the actual mechanism for any observed changes is not explicitly known. One reason for the lack of conceptual change with analogy teaching is that, whilst the teacher's analogy is based on propositionally based knowledge, the student's is built on mental images (Wilbers and Duit 2006).

An Ontological Perspective of Conceptual Change

Researchers who use epistemology to explain conceptual changes do not overtly emphasise changes in the way in which students view reality. Other researchers do use specific ontological terms to explain changes in the way students develop their science conceptions (Chi 2008). Two candidates for these types of change are heat, which needs to change from a flowing fluid to energy in transit, and a gene, which needs to change from an inherited object to a biochemical process. There are many other concepts for which scientists' *process* views are incommensurable with students' *material* conceptions and the desired changes to students' ontologies are not often achieved in school science. For example Mei-Hung Chiu and her colleagues (2002) adopted Chi's ontological categories of scientific concepts in investigating how students perceive the concept of chemical equilibrium, arguing that 'although Posner's theory is widely accepted by science educators and easy to comprehend and apply to learning activities, … it does not delineate what the nature of a scientific concept is, which causes difficulty in learning the concept' (p. 689).

Affective/Social Aspects and Learner Characteristics of Conceptual Change

The third focus of conceptual change is the affective domain, particularly involving emotions, motivation and social aspects, such as group work, and learner characteristics, such as students' self-efficacy and control beliefs; the classroom social context and the individual's goals, intentions, purposes, expectations and needs are as important as cognitive strategies in concept learning (Pintrich et al. 1993). Group factors also can advantage concept learning and Vygotsky's theories recognise the importance of social and motivational influences.

Studies reported in Gail Sinatra and Paul Pintrich (2003) emphasised the importance of the learner, suggesting that the learner should play an active and intentional role in the process of knowledge restructuring. Whilst acknowledging the important contributions to the study of conceptual change from the perspectives of science education and cognitive developmental psychology, Sinatra and Pintrich note that the psychological and educational literature of the 1980s and 1990s placed greater emphasis on the role of the learner in the learning process. However, whilst there is strong support for the ideas, initiated by Paul Pintrich et al., that there is more to conceptual change than cognition, especially in the use of theoretical models as explained by Gail Sinatra and Lucia Mason (2008), there are still few empirical studies of the relationship between these factors and conceptual change.

Indeed, teachers who ignore the social and affective aspects of personal and group learning might limit conceptual change in their classrooms; we come back to this point in the second part of this chapter. In a review linking the cognitive and the emotional in teaching and learning science, Michalinos Zembylas (2005) goes a step further by arguing that it is necessary to develop a unity between cognitive and emotional dimensions in which emotions not only are moderating variables of cognitive outcomes, but also a variable of equal status. Zembylas advocates research in which affective variables are deliberately developed and undergo conceptual changes; but not many empirical studies incorporating affective variables are available. As noted by Steve Alsop and Mike Watts (2003), the effect of affect on learning science is an 'often overlooked domain' (p. 1044).

Impact of Conceptual Change Research on School Practice

In principle, from the extant research on conceptual change, there is a large potential for improving practice in the science classroom. However, so far, the research evidence concerning the impact of teaching informed by conceptual change instructional practices in normal classes is limited and tends to be associated with various teacher factors. We address these factors in the following paragraphs.

Teachers' Views of Teaching and Learning Science

One of the major obstacles to success in implementing science standards in the United States is that teachers usually are not well informed about the recent state of research on teaching and learning science and hold views of teaching and learning that are predominantly transmissive and not constructivist (Anderson and Helms 2001). Indeed, research has shown that many teachers hold conceptions of science concepts and processes that are not in accordance with the science view and often are similar to students' pre-instructional conceptions. Research has also shown that many teachers hold limited views of the teaching and learning process (Duit et al. 2007) and of the nature of science (Lederman 2007). Hence, teachers' conceptions of various kinds also need to undergo conceptual changes. Basically, the same conceptual change frameworks for addressing students' conceptions have proven valuable for developing teachers' views of science concepts (Hewson et al. 1999a, b).

Many studies of teachers' views about teaching and learning carried out since the 1990s suggest that it is essential to encourage science teachers to become familiar with the recent state of educational research and to help them to develop their views about efficient teaching and learning. Analysis of videotapes on the practice of German and Swiss lower secondary physics instruction showed that most teachers are not well informed about key ideas of conceptual change research (Duit et al. 2007). Teachers' views of their students' learning usually are not consistent with recent theories of teaching and learning. Indeed, many teachers appear to lack an explicit view of learning. Several teachers hold implicit theories that contain some intuitive constructivist issues; for instance, they are aware of the importance of students' cognitive activity and the interpretational nature of students' observations and understanding. However, teachers were identified who characterised themselves as mediators of facts and information and who were not aware of students' interpretational frameworks and the role of students' pre-instructional conceptions. These teachers mostly think that what they consider to be good instruction is a guarantee for successful learning.

Are Conceptual Change Approaches More Efficient Than More Traditional Ones?

Usually researchers who use a conceptual change approach in their classroom-based studies report that their approach is more efficient than traditional ones. Efficiency exclusively or predominantly involves cognitive outcomes of instruction. The development of affective variables during instruction is often not viewed as an intended outcome (Murphy and Alexander 2008). In summarising the state of research on the efficiency of conceptual change approaches, there appears to be ample evidence in various studies that these approaches are more efficient than traditional approaches dominated by transmissive views of teaching and learning. This seems to be the case, particularly if more inclusive conceptual change approaches, based on multidimensional perspectives as outlined above, are employed.

Recent large-scale programmes for improving the quality of science instruction (as well as instruction in other domains) include instructional methods that are oriented towards attempts to implement constructivist principles of teaching and learning into practice (Beeth et al. 2003). Three other characteristics of high-quality development approaches referred to by Michael Beeth et al. (2003) are: the need to support schools and teachers in rethinking the representation of science in the curriculum; the necessity to enlarge the repertoire of tasks, experiments, and teaching and learning strategies and resources; and showing how to promote strategies and resources that attempt to increase students' engagement and interests. This set of characteristics requires teachers to be reflective practitioners (Schon 1983) with a non-transmissive view of teaching and learning. Students need to be seen as active, self-responsible, cooperative and self-reflective learners. Indeed, these features are at the heart of inclusive constructivist conceptual change approaches.

The Practice of Teaching Science in Normal Classes

In summarising findings of student narratives from interpretive studies of students' experiences of school science in Sweden, England and Australia, Lyons (2006, p. 595) noted that 'students in the three studies frequently described school science pedagogy as the transmission of content expert sources – teachers and texts – to relative passive recipients'. Students were overwhelmingly critical of this kind of teaching practice, leaving them with an impression of science as being a body of knowledge to be memorised. The normal practice of science instruction described in the above studies was not significantly informed by constructivist conceptual change perspectives. Of course, there was large variance within the educational culture of certain countries and also between the educational cultures of the countries. But still there is a large gap between instructional design based on recent research findings on conceptual change and what is normal practice in most of the classes observed.

Conceptual Change and Teacher Professional Development

Investigating teachers' views of teaching and learning science and the means to improve teachers' views and their instructional behaviour through teacher professional development has developed into a research domain that has been given much attention since the late 1990s (Borko 2004). Two major issues are addressed in teacher professional development projects. First, teachers become familiar with research knowledge on teaching and learning by being introduced to recent constructivist and conceptual change views, and then they become familiar with instructional design that is oriented towards these views. Second, attempts to link teachers' own content knowledge and their pedagogical knowledge play a major role. The most prominent theoretical perspective applied is Shulman's (1987) idea of content-specific pedagogical knowledge or Pedagogical Content Knowledge (PCK, Abell, 2007).

It is important to note, however, that attempts to explicitly employ the more recent multidimensional and inclusive conceptual change perspectives, as outlined in the first part of the present chapter, currently appear to be missing. Clearly, Peter Hewson et al. (1999a, b) take into account teacher change processes of various kinds, but the conceptual change perspectives applied appear to be largely concerned with teachers' epistemologies.

Further Developments Needed to Enhance Conceptual Change Research in Science Education

We believe that researchers of conceptual change in science education can greatly contribute to this field of activity by investigating conceptual change from multidimensional perspectives; paying more attention to the context of learning; acknowledging the importance of dialogue in facilitating learning; emphasising the need for replication studies; and determining the necessary and sufficient evidence for identifying conceptual change. We discuss each of these points in this section.

Investigating Conceptual Change from Multidimensional Perspectives

Conceptual change approaches as developed in the 1980s and early 1990s contributed substantially to improving our understanding of science learning and teaching. Most of the early studies of learning science were oriented towards the epistemological views of learning and ignored other existing views such as Michelle Chi's ontological categories and Stella Vosniadou's framework theory. However, the latter perspective appears to have had little influence in encouraging science education researchers to follow these lines of research. Similarly, there is ample evidence in research on learning and instruction that cognitive and affective issues are closely linked. However, the number of studies of the interaction of cognitive and affective factors in the learning process is limited, except for studies of correlations between interest in science and cognitive results of learning. The interplay of changes of interest in science and conceptual change has been investigated only in a small number of studies.

Our view is that research on conceptual change approaches needs to take into account multiple perspectives and focus on ways in which the various theoretical perspectives are linked and can constructively interact in a complementary way. On the theoretical plane, individuals construct mental models which are consistent with theories that involve internal representations in thinking processes. Indeed, cognitive scientists view models as internal representations that reflect external reality and that are built from prior knowledge, perceptions, schema and problem-solving strategies.

By the very nature of an individual acting in his or her social environment, a single perspective, no matter how well argued, cannot identify the nature of these interactions (Duit and Treagust 1998, 2003; Greeno et al. 1997). One perspective is likely to miss more than is identified. In the study by Venville and Treagust (1998), for instance, science learning was investigated from four different theoretical positions of conceptual change. Each theoretical position (e.g. an epistemological position or an ontological perspective) enabled identification of learning issues that another theoretical approach did not. In a similar vein, Tiberghien (2008) argues that a theory which does not take into account different components – social situation, kinaesthetic perceptions, type of knowledge, types of lexical and syntactical forms of language – is not relevant to her research programme. Briefly summarised, multi-perspectives of conceptual change that encompass epistemological, ontological and affective domains have to be employed in order to adequately address the complexity of teaching and learning processes.

In contrast to the approach of being committed to one theoretical perspective of conceptual change as a framework for their data analysis and interpretation, Venville and Treagust (1998) utilised different perspectives of conceptual change – epistemological, ontological and affective – in analysing different classroom teaching situations in which analogies were used to teach genetics. Venville and Treagust (1998) found that each of the perspectives of conceptual change had explanatory value and enabled different theoretical frameworks for interpreting the role that analogies play in each of the classroom situations.

Paying More Attention to the Importance of Context in Learning

In the debates about conceptual change in *Cultural Studies in Science Education*, one of the points made by the social scientists was the importance of describing the context in more detail than is usual. In the chapters in Vosniadou (2008), whilst some authors (e.g. Brown and Hammer 2008, p. 135) state that 'there is a wide consensus … that at least some of the misunderstandings [of physics concepts] vary with context', there is little discussion of context throughout this volume.

Context in learning involves both the internal context as perceived by the learner and the external context of the discourse presented. From a sociocultural perspective, there is a need to recognise the importance of the emotions/affective domain as well as learner characteristics. The affective aspect of learning is much overlooked and its inclusion is encouraged when using a broader socio-cultural framework. A multi-perspective position of conceptual change recognises the importance not only of the context in which teaching and learning happens, but also of the environment in which student interviews or interactions take place in interpreting findings about conceptual change.

Acknowledging the Importance of Dialogue in Facilitating Learning

A key issue from the cultural studies aspects of conceptual change is the importance of dialogue. Learning is always deeply shaped by the particular social and material characteristics of the learning environment (Wells 2008). Hence, the discourse in small-group inquiry, individual learning or whole-class instruction is essential for discerning the quality of the learning outcomes (Duit et al. 2008). Further, we have discussed previously (Duit et al. 1996) the importance of co-construction of knowledge in exchanges between interviewer and interviewee.

Emphasise the Need for Replication Studies

In their synthesis and meta-analysis of research on conceptual change reported in the 5-year period, 2001–2006, Murphy and Alexander (2008, p. 584) considered conceptual change as 'a latent variable … a theoretical variable that cannot be directly observed or measured but is presumed to exert influence on other observable variables such as learning or achievement'. Their detailed analysis, which included 20 of an original 47 studies meeting specified criteria, supported the conceptual change models of Posner et al. and Vosnaidou. However, Murphy and Alexander reported few replication studies and that most studies included in the analysis were single interventions without the benefit of repeat trials.

Determining the Necessary and Sufficient Evidence for Identifying Conceptual Change: Towards Mixed-Methods Studies

In approaches near to the classical conceptual change model, data collection includes written tests, interviews and, less frequently, thinking-aloud protocols; however, this is developmental research and not conceptual change research. Because studies need to show how concepts have changed over time, it is usually necessary to include a quasi-experimental research design that involves pre- and post-measures and preferably continuous kinds of data. These process studies have shown evidence of conceptual change. The importance of good dialogue and detailed and careful analysis is crucial to making claims about conceptual change. Whilst recognising the importance of dialogue in investigating a student's conceptual change as he or she interacts with a teacher or a fellow student, Mercer (2008) also emphasises the need for conceptual change researchers to consider more deeply how both social and cognitive aspects of dialogue contribute to conceptual change.

Concluding Comments

This chapter discussed three distinct but closely connected issues concerning conceptual change in science. First, we discussed theoretical perspectives of conceptual change and illustrated how researchers have conceptualised teaching and learning science from these different perspectives. Second, we reported implemented conceptual change teaching and learning approaches and examined the degree of success of these interventions. Third, we suggested how conceptual change research involving science domains can be improved.

The state of theory building on conceptual change has become more and more sophisticated and the teaching and learning strategies developed have become more and more complex over the past 30 years. Whilst these developments are necessary to address the complex phenomena of teaching and learning science more adequately, there has been an increase in the gap between what is necessary from researchers' perspectives and what might be set into practice by normal teachers. Therefore, a paradox arises in that, in order to adequately model teaching and learning processes, research alienates the teachers and hence widens the theory-practice gap. However, we should deal with this paradox by developing theoretical frameworks, more finely focused research methods, and more efficient conceptual change instructional strategies. Fortunately, the frameworks for studying student conceptual change – being predominantly researched so far – also might provide powerful frameworks for teacher change towards employing conceptual change ideas. We believe that more research based on inclusive conceptual change perspectives is most desirable.

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Chapter 10
Reframing the Classical Approach to Conceptual Change: Preconceptions, Misconceptions and Synthetic Models

Stella Vosniadou

The Problem of Conceptual Change in Science Learning

The idea that the learning of science could require conceptual change was first introduced by George Posner and his colleagues (Posner et al. 1982; see also McCloskey 1983) in order to explain students' difficulties in understanding science concepts. Since the late 1970s, many science educators (e.g. Driver and Easley 1978; Viennot 1979) became aware of the fact that students bring to the science learning task alternative frameworks or misconceptions that are robust and difficult to extinguish through teaching. Posner et al. (1982) proposed that the learning of science requires the replacement of such persistent misconceptions. They drew an analogy between Jean Piaget's concepts of assimilation and accommodation, and the concepts of normal science and scientific revolution offered by philosophers of science such as Thomas Kuhn (1962), and derived from this analogy an instructional theory to promote 'accommodation' in students' learning of science. According to Posner et al. (1982), there are four fundamental conditions that need to be fulfilled before conceptual change can happen in science education: (1) there must be dissatisfaction with existing conceptions; (2) there must be a new conception that is intelligible; (3) the new conception must appear to be plausible and (4) the new conception should suggest the possibility of a fruitful programme.

This theoretical framework, known as the *classical* approach to conceptual change, became the leading paradigm that guided research and instructional practices in science education for many years. In the classical approach, conceptual change is considered to be the result of a rational process of theory replacement by learners who are like scientists. It is supposed to take place in a short period of time – it is considered as something like a gestalt-type restructuring. According to this approach, the main

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impediments to understanding scientific concepts are the four conditions named earlier. For this reason, within the classical approach, conceptual change was to be achieved mainly through the creation of cognitive conflict. Thus, cognitive conflict became the major instructional strategy for producing conceptual change.

Over the years, practically all of the above-mentioned tenets of the classical approach were subjected to serious criticism. Some researchers argued that conceptual change is slow and gradual and not a dramatic gestalt-type shift (Carvita and Halden 1997); that learners are not exactly like scientists in that they do not understand that their beliefs are hypotheses that need to be tested (Vosniadou 2003); that affective and motivational factors have an important role to play in conceptual change (Sinatra and Pintrich 2003) and that conceptual change is significantly influenced by social processes (Hatano and Inagaki 2003).

In addition to the above, Jack Smith et al. (1993) criticised the use of cognitive conflict on the grounds that it presents a narrow view of learning that focuses only on the mistaken qualities of students' prior knowledge and ignores their productive ideas that can become the basis for achieving a more sophisticated scientific understanding. Smith et al. (1993) argued that misconceptions should be reconceived as faulty extensions of productive knowledge, that misconceptions are not always resistant to change, and that instruction that 'confronts misconceptions with a view to replacing them is misguided and unlikely to succeed' (p. 153).

Since then, Andy diSessa (1988, 1993, 2008) put forward a different proposal for conceptualising the development of physical knowledge. He argued that the knowledge system of novices consists of an unstructured collection of many simple elements known as phenomenological primitives (*p-prims* for short) that originate from superficial interpretations of physical reality. P-prims appear to be organised in a conceptual network and to be activated through a mechanism of recognition that depends on the connections that p-prims have to the other elements of the system. According to this position, the process of learning science is one of collecting and systematising these pieces of knowledge into larger wholes. This happens as p-prims change their function from relatively isolated, self-explanatory entities to become integrated into a larger system of complex knowledge structures such as physics laws. In the knowledge system of the expert, p-prims 'can no longer be self-explanatory, but must refer to much more complex knowledge structures, physics laws, etc. for justification' (diSessa 1993, p. 114).

diSessa (1993) and Smith et al. (1993) provide an account of the knowledge-acquisition process that captures the continuity that one expects with development and has the possibility of locating knowledge elements in novices' prior knowledge that can be used to build more complex knowledge systems. We agree with them about the need to move from thinking of conceptual change as involving single units of knowledge to systems of knowledge that consist of complex substructures that can change gradually and in different ways. Finally, we agree with Smith et al.'s (1993) recommendation to researchers to 'move beyond the identification of misconceptions' towards research that focuses on the evolution of expert understandings and particularly on 'detailed descriptions of the evolution of knowledge systems over much longer durations than has been typical of recent detailed studies' (p. 154).

For a number of years now, we have been involved in a programme of research that attempts to provide detailed descriptions of the development of knowledge in specific subject-matter areas, especially the physical sciences, such as astronomy (Vosniadou and Brewer 1992, 1994; Vosniadou and Skopeliti 2005; Vosniadou et al. 2004, 2005), mechanics (Ioannides and Vosniadou 2002), geology (Ioannidou and Vosniadou 2001), biology (Kyrkos and Vosniadou 1997) and mathematics (Vosniadou and Verschaffel 2004). Our studies are mostly cross-sectional developmental studies into the knowledge-acquisition process in students ranging from 5 to 20 years of age. We have also used the results of our research to develop curricula and instruction that has been tried out in schools in Greece (Vosniadou et al. 2001). The results of these studies have led us to the development of a revised framework for thinking about conceptual change in the learning of science (Vosniadou et al. 2007, 2008). In the pages that follow, we outline the main tenets of this approach, which we will call the *framework theory* approach, highlighting its similarities and differences with the *classical approach* to conceptual change as well as with diSessa's *knowledge in pieces* position. Examples are given from cognitive, developmental and science education research focusing mainly on the concepts of the earth and of matter.

The Framework Theory Approach

Preconceptions Are Different from Misconceptions

Unlike the classical approach, the framework theory approach makes a fundamental distinction between *preconceptions* and *misconceptions* and considers many misconceptions to be synthetic conceptions or models. We consider preconceptions to be the initial ideas about the physical world and explanations of physical phenomena that children construct on the basis of their everyday experience in the context of lay culture *before they are exposed to school science*. On the contrary, we consider misconceptions to be students' erroneous interpretations of the scientific concepts *after they are exposed to school science*. We explain later in this chapter exactly in what way we consider misconceptions to be synthetic.

There is a great deal of cognitive developmental and science education research showing that young children, who have not yet been exposed to science, answer questions about force, matter, heat, the day/night cycle, etc. in a relatively consistent way that reveals the existence of initial conceptions or preconceptions (Baillargeon 1995; Carey and Spelke 1994; Gelman 1990). For example a substantial body of research supports the conclusion that, during the preschool years, children construct an initial concept of the earth based on interpretations of everyday experience in the context of lay culture. According to this initial concept, the earth is a flat, stable, stationary and supported physical object. Space is organised in terms of the dimensions of up and down and objects on the earth (the earth itself included) fall down when they are not supported (up/down gravity concept). The sky and solar objects are located above the top of this flat earth that is thought to occupy a geocentric universe (Vosniadou and Brewer 1992, 1994; Nussbaum, 1979, 1985).

Similarly, a great deal of research has shown that, before they go to primary school, many children have already constructed an initial concept of matter or material kind that is different from the concept of physical object (Carey 1991; Wiser and Smith 2008). They group solids, liquids and powders together as consisting of some kind of stuff, distinguishing them from gases (air) and nonmaterial entities (heat, electricity) or mental entities (ideas, wishes). These material entities are things that can be seen, touched and felt, and produce some kind of physical effects. Similar results can be found for biology (Carey 1985; Hatano and Inagaki 1997), mechanics (Ioannides and Vosniadou 2002; Chi 1992, 2008) and heat and temperature (Wiser and Amin 2001) amongst others.

Preconceptions Cohere

Children's initial conceptions, or preconceptions, are not superficial beliefs but represent a coherent, although relatively narrow, explanatory *framework theory* that some call intuitive or naïve. The term *theory* is used loosely to denote a network of interrelated beliefs that can be used to provide explanations and form predictions and not a fully developed scientific theory. For example, studies of children's explanations of the day/night cycle show that most children are capable of providing a mechanism to explain the alternation of day and night before they are exposed to the scientific explanation. They say, for instance, that the sun goes behind the mountains during the night, or behind clouds, and the moon comes up (Vosniadou and Brewer 1994). They also use this mechanism productively to answer generative questions – that is they are capable of saying that if we wanted to have day all the time in our part of the world, then we should prevent the sun from moving. They can also make predictions, such as that the moon cannot be in the sky during the day, which are often wrong and which can be exploited instructionally (i.e. when falsified, they can lead to cognitive conflict). Unlike scientists, however, children are usually not metaconceptually aware of their beliefs and they do not understand that they represent hypotheses that can be falsified.

Preconceptions Are Different in Their Ontology and Epistemology from Scientific Theories

The initial conception of a flat earth is deeply rooted in young children's categorisation of the earth as a physical object (as shown experimentally in Vosniadou and Skopeliti 2004) that has all the characteristics of physical objects, such as solidity and lack of self-initiated movement. Like other physical objects, it is conceptualised in the context of a space organised in terms of the directions of up and down and in which gravity operates in an up/down fashion. Understanding the scientific concept of the earth requires children to recategorise the earth from the ontological category of ‘physical object’ to the ontological category of ‘physical-astronomical object’. In other words, they have to think of the earth as a planet in space and not as a solid ground distinct from other astronomical objects. Our studies show that such recategorisations happen in the conceptual system of elementary school children between third and sixth grade (Vosniadou and Skopeliti 2005). Such recategorisations also require some epistemological sophistication and understanding of models, as they depend on children’s ability to understand how their initial, perceptually based representations of the earth are related to the conceptually based model of a spherical earth in space.

Similarly, children’s initial conception of matter is perceptually based. As Marianne Wiser and Carol Smith (2008) argue, an entity is material (made of some stuff) if it can be touched and seen. It can be thought of as being composed of homogeneous parts that are touchable and visible as well, or else they could not compose matter. Understanding the atomic theory of matter requires radical ontological shifts to take place, since atoms, although the sole constituents of matter have many counterintuitive properties, such as that they exist in vacuum and move in high speeds. Similar arguments are made by other researchers. For example Michelene Chi (1992) argues that ontological shifts are necessary for understanding many science concepts, such as the concepts of force, energy and heat. These concepts are all categorised as entities or substances in the initial conceptual system of novices but are recategorised as processes in the conceptual system of experts. Giyo Hatano and Kayoto Inagaki (1997) also offer examples of changes in ontology and causality in children’s acquisition of biological knowledge. Furthermore, these changes cannot be achieved without developing the ability to reason on the basis of theoretical models and an understanding of how such models relate to experimental evidence.

Conceptual Change Is Not a Sudden, Gestalt-Like Replacement of One Concept with Another

Unlike the classical approach, we do not believe that conceptual change can be achieved through some kind of sudden replacement of the initial conception with a scientific concept when the student becomes dissatisfied with it. Although some sudden restructurings might be possible in some cases, conceptual change is for the most part a slow process not only because it involves a complex network of interrelated concepts (Smith et al. 1993), but also because it requires the construction of new representations that, as we discussed earlier, involve radical changes in ontology and epistemology.

Conceptual change is achieved gradually as new ideas are added onto existing but conflicting conceptual structures sometimes enriching them and sometimes fragmenting them. Indeed, school science can often lead students to greater internal inconsistency and fragmentation in ways that are not often recognised by the science education community. It can also lead to the formation of misconceptions, many of which can be interpreted as synthetic conceptions or models.

Many Misconceptions Are Synthetic Conceptions or Models

We argue that many misconceptions are synthetic conceptions or models that are produced when students are exposed to scientific explanations without adequate instruction. As we have argued before (Vosniadou et al. 2008), misconceptions are often created as students unconsciously apply enrichment types of learning mechanisms to add scientific information to an existing but incompatible prior knowledge. For example in astronomy, children come to believe that the earth is a flattened or a truncated sphere with people living only on its flat top. Or, they might think that the earth is a hollow sphere with people living on flat ground inside it whilst the sky covers them on top like a dome (Vosniadou and Brewer 1992). All of these misconceptions can be seen as representing children's constructive attempts to synthesise the scientific information that the earth is a sphere with some of the beliefs that constitute their initial conceptions and which act as constraints in the knowledge-acquisition process. Some of these beliefs are that the ground is flat and that physical objects must be supported otherwise they will fall down.

Similar synthetic conceptions can be observed in children's attempts to understand the atomic theory of matter. An extremely powerful misconception that survives even through the college years is the belief that atoms are not the basic constituents of matter, but rather something *in* matter, as embedded in a material substrate (Anderson 1990; Pozo and Gomez Crespo 2005). The *matter-in-molecules model* is a synthetic model resulting from the integration of school information with students' initial conceptions. It is successful in integrating the new scientific information that matter consists of atoms, without fundamentally altering their original realistic representation of matter as something inherently continuous.

Unfortunately, traditional instruction does not always provide students with the necessary background information or with the tools that are necessary in order to acquire the new ontological categories and move from their epistemologically naïve and perceptually based explanations to an understanding of complex, conceptual models in science. Furthermore, sometimes the instruction provided reinforces the formation of misconceptions such as the ones mentioned earlier. For example, the language used in many textbooks, such as 'Atoms *in* solids vibrate, while atoms *in* liquids …', 'Molecules are less free to move *in* ice than *in* (liquid) water', Bonds are the *glue* between atoms', etc. reinforce the matter-in-molecules misconception. The same applies to textbook illustrations which present pieces of substances as coloured cubes with small black spheres (atoms) inside them (Wiser and Smith 2008).

Conceptual Change Requires Fundamental Changes in Students' Representations and in Ontological and Epistemological Commitments

These changes are not in place by the time the scientific theories are presented to students. For example understanding the scientific concept of the earth requires changing from a representation of a stable, flat, supported earth consisting of ground all the way down, to the representation of a spherical earth in space, rotating around its axis, and revolving around the sun. Such a representation is not created simply by presenting children with the model of a globe, as it is usually done. As we have shown in previous work (Vosniadou et al. 2005), understanding a conceptual model is an act of interpretation that is constrained by prior knowledge. Although children see the globe, they often do not understand how it relates to the perceptually experienced earth. As a result, they often distort the model to agree with their initial conceptions (e.g. the earth is flat or that gravity operates in an up/down fashion). These preconceptions act as strong constraints and limit their understanding of the scientific concept. Understanding the scientific concept requires explaining to children how it is possible for the earth to be flat and round at the same time, and how it is possible for people to live on this globe without falling down – a change in children's up/down gravity concept.

As mentioned earlier, the scientific concept and its related conceptual representation are not there to replace children's naive, perceptually based representation of the earth. On the contrary, children need to develop the ability to take different perspectives, perspectives from deep space or from evolutionary time, and understand how their phenomenal, naive conceptions are related to the scientific concepts which provide more powerful explanations of physical phenomena. Science instruction should be provided to move children from an epistemology based on naive realism and the belief that things are as they appear to be. Children need to develop an understanding of the nature and function of models and the processes of scientific reasoning through hypothesis testing and falsification and through extensive experience in model construction and revision.

Similarly, in the case of the concept of matter, students need to change from a naive representation of matter as a continuous entity to the atomic model. Again, this is a conceptual model that requires children to understand the distinction between perceptual and physical properties and how they are linked. The children would need to form the concept of emerging properties and understand how atoms, invisible to the naked eye, can form matter with physical and perceptual properties. Here again children need to move from an epistemology of naive realism and to understand that there is a macroscopic level which is related to and explains the macroscopic phenomena.

In summary, conceptual change in both of these domains requires substantial acquisition of new knowledge, the creation of new ontological categories and substantial reorganisation of existing conceptual structures. It also requires the development of epistemological sophistication and the understanding of the role of conceptual models in science and of hypothesis testing and falsification.

Relation to Other Approaches

Our synthetic models approach meets all the criticisms of the classical approach made by Carol Smith et al. (1993). First, we are not describing unitary, faulty conceptions but a knowledge system consisting of many different elements organised in complex ways. Second, we make a distinction between initial explanations prior to instruction and those that result after instruction and which we call synthetic models. Synthetic models are not stable but dynamic and they are constantly changing as children's developing knowledge systems evolve. Finally, our theoretical position is a constructivist one. It can explain how new information is built on existing knowledge structures and provides a comprehensive framework within which meaningful and detailed predictions can be made about the knowledge acquisition process.

Finally, our position is not inconsistent with the view that something like diSessa's p-prims constitute an element of the knowledge system of novices and experts. We believe that p-prims can be interpreted to refer to the multiplicity of perceptual and sensory experiences that are obtained through our observations of physical objects and our interactions with them. These perceptual experiences provide the basis, in the context of lay culture, for the construction of beliefs, presuppositions and mental models (i.e. of a conceptual system). A conceptual system is an organised knowledge structure, no matter how loose or naïve this initial organisation might be. Thus, the process of learning science is not one of simply organising the unstructured p-prims into physics laws but rather one during which preconceptions become re-organised into a scientific theory. This is a slow, gradual process which can cause misconceptions or synthetic models – a phenomenon which is not explained by the knowledge in pieces approach.

Implications for the Design of Curricula and Instruction

Following what we have already said regarding students' difficulties in learning science, we do not believe that instruction based only on cognitive conflict is adequate. Although limited uses of cognitive conflict can be useful in motivating students to learn, instruction for conceptual change needs to be designed carefully, for the long run, and to be based on research that shows the learning progression that students follow as they slowly change their initial conceptions to understand science.

In view of students' difficulties in learning science, it might be more profitable to design curricula and focus on the deep exploration of a few key concepts in one subject matter area rather than to cover a great deal of material in a superficial way. Some science curricula include short units on mechanics, energy, particulate nature of matter, processes of life, etc. This approach does not give students enough time to achieve the qualitative understanding of the concepts being taught. On the contrary, it encourages the causal memorization of facts and it is likely to lead to logical incoherence and misconceptions.

It is also important when designing curricula to distinguish new, scientific, information that is consistent with what students already know or believe from new information that runs contrary to students' conceptions. When the scientific information is consistent with what students already know, it can be easily incorporated into existing knowledge structures. But when it is not, it is very likely that it will be misunderstood. Thus, curriculum developers and teachers should utilise the findings of existing cognitive science and science education research so that they can pay particular attention to those initial conceptions and misconceptions of students that have been found to be persistent and difficult to extinguish. Because these conceptions can constrain the understanding of the scientific concepts, curricula should be designed to provide especially clear explanations, experiments, observations, models, etc. that would help students to restructure their prior knowledge (Vosniadou et al. 2001).

Instruction-induced conceptual change requires not only the restructuring of students' naïve theories, but also the restructuring of their modes of learning and reasoning, the creation of metaconceptual awareness and intentionality, and the development of epistemological sophistication (Sinatra and Pintrich 2003). There are several aspects of intentional learning that can be promoted in order to foster conceptual change and which we highlight below.

Cognitive developmental research suggests that students are not always aware of the beliefs and presuppositions underlying their reasoning and, even more important, they do not realise the hypothetical nature of these beliefs. Instruction should support students in realising the hypothetical nature of their beliefs and teach them how to test them and evaluate their explanatory power. Students' views of science as a discipline have an impact on the way in which they approach learning in the domains. If students believe that science provides a true picture of the state of affairs about the world (Driver et al. 1994), then they are less likely to develop critical thinking, engage in hypothesis testing or look for alternative explanations. Instead, they are more likely to rely on the he authority of the teacher or of the text. Christina Stathopoulou and Stella Vosniadou (2007) have shown that there is a strong correlation between students' epistemic beliefs and the way in which they approach studying in physics. Students who believe that knowledge is stable and certain and consists of pieces of information are more likely to adopt superficial, rather than deep, study strategies, and they are less likely to achieve conceptual change in mechanics (see also Mason 2003; Mason and Gava 2007).

The use of analogies, models and cultural artefacts is considered a significant component of powerful learning environments. However, it should be taken into consideration that the mere presence of such tools is not enough to mediate effective learning. External representations and conceptual models are interpreted on the basis of students' prior knowledge, and sometimes they are not interpreted correctly (Vosniadou et al. 2005). A problem with representations, in general, is that they are transparent to those who understand them and opaque to those who do not. Instruction needs to be developed to help students understand better the nature and function of models and engage in model-based reasoning.

As Hatano and Inagaki (2003) argue, this type of instruction cannot be achieved without substantial sociocultural support. One way in which teachers can provide the sociocultural environment to encourage comprehension is to ask students to participate in dialogical interaction, which is usually whole-class discussion. Whole-classroom dialogue can be effective because it ensures that students understand the need to revise their beliefs deeply instead of engaging in local repairs (Chinn and Brewer 1993) and that they spend the considerable time and effort needed to engage in the conscious and deliberate belief revision required for conceptual change (see also Miyake 2008). Another way is to ask, students to break up into smaller groups that compete with each other in discovering the correct solution and supporting it with the best arguments. This division of labour creates what Hatano calls ‘partisan’ motivation which amplifies ‘cognitive’ motivation and enhances deep comprehension and intentional learning (Hatano and Inagaki 2003).

Conclusion

It has been argued that students construct initial explanations of physical phenomena which are embedded in loosely organised but nevertheless relatively coherent explanatory frameworks which can constrain science learning. The learning of science requires substantial conceptual changes to take place in students’ initial conceptions as they are exposed to school science. Although these changes can be achieved through enrichment types of mechanisms, the assimilation of scientific information into students’ incompatible knowledge structures not only makes science learning very slow, but it also creates internal inconsistency and misconceptions. Many of these misconceptions are ‘synthetic models’ resulting from students’ constructive but inappropriate attempts to synthesise scientific information with incompatible initial knowledge, but without metaconceptual awareness. In order to achieve the learning of science in ways that avoid internal inconsistency and synthetic models, there needs to be provided instruction that gives students all the necessary information required to reorganise their ontological categories, whilst also developing epistemological sophistication and the hypothesis testing skills. It is important for students to move from their naive, perceptually based epistemologies to an understanding of conceptual models in science and to develop the top-down, deliberate and intentional learning mechanisms that scientists use for hypothesis testing. These changes cannot be achieved by cognitive means alone but require extensive sociocultural support.

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Chapter 11
Metacognition in Science Education: Past, Present and Future Considerations

Gregory P. Thomas

Introduction

This chapter builds on Richard White's (1998) chapter in the previous edition of this *International Handbook of Science Education*. In that chapter, White focused on decisions and problems in research on metacognition. My intention in writing this chapter is to review progress in the area of metacognition over the past 10 or so years, particularly in science education, but also, as space permits, across the fields of education and cognitive psychology in general. My reasons for drawing broadly from the literature for this chapter relate to a growth in interest in the study of metacognition across education and psychology that is evident, for example, in the establishment of a Special Interest Group (SIG) on metacognition within the European Association for Research on Learning and Instruction (EARLI) and the publication of the journal *Metacognition and Learning*, the flagship publication of that SIG. Importantly, research in science education in the field of metacognition continues to draw on insights regarding metacognition from other areas, particularly cognitive psychology. In fact, Hacker (1998) considers that studies on metacognition in education are an emerging fourth category of metacognitive research alongside studies of cognitive monitoring, cognitive regulation, and cognitive monitoring and regulation. Therefore, it is reasonable to highlight, as necessary, significant contributions to understanding metacognition from outside science education and to consider how these might be useful for moving forward with research and scholarship on metacognition within our field. My intention is for those reading this chapter to come more fully to understand metacognition as it relates to the field of science education so that students' learning processes and consequently their science learning might be improved.

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There is good reason to suggest that Richard White's (1998) concern regarding the quality of learning of science is still relevant to science education today. There is little evidence that the quality of students' learning of science has improved over the past decade or so. That this concern persists is itself a concern because it suggests that what we already know about how to improve science education and learning through the enhancement and development of students' metacognition is not finding its way into either the everyday practice of classroom teachers or the mindset and/or curricula of teacher educators and their teacher education programmes. In other words, whilst there are few who question the importance of metacognition, the recognition of this importance is not reflected in teachers' or teacher educators' practices. It has become increasingly evident that metacognition is a key to attending to the multiple agendas that characterise science education today. These agendas include the development of students' scientific literacy and their understanding of the nature of scientific inquiry, the nature of science itself and science concepts. For example to be able to undertake a process of scientific inquiry, there is a need for students to be able to consciously undertake particular procedures, both physical and cognitive, to monitor their progress towards the goal/s of the inquiry as they proceed, be aware of and evaluate their progress, and reflect on the outcomes of their inquiry with a view to improving their practices. This type of conscious thinking is the hallmark of a metacognitive individual. Further, as highlighted by Richard Gunstone (1994), metacognitive students are central to constructivist learning environments where students should continuously monitor new information that is presented to them and compare it with what they already know from their previous learning. It is such a constant and conscious reflection that is at the heart of conceptual change theories in science education.

Despite these obvious examples of how metacognition is important in science education, it remains a fringe area of study within the field that deserves increased attention. There are good reasons for this status, as White (1998) suggests. Indeed, as we have come to know more about metacognition and as more scholars have become involved in its study, new areas of contention have arisen, old debates have persisted to varying extents, and discussion continues about exactly what metacognition is, how it can be measured, and how best to bring about the development and enhancement of metacognition in students. Even though progress on these substantive matters has been uneven, there is agreement that, across science education and in education in general, metacognition is a useful predictor of successful learning. In what follows, I explore some of the issues and debates surrounding metacognition. It is through exploring these debates that readers can identify their own contentions and positions in relation to the field of metacognition as it currently stands. In other words, rather than promote a single view, I aim to highlight the diversity of opinions and attend to some contentious issues in this field in an attempt to promote and initiate further debate. No doubt, some readers will disagree with my positions on a number of matters. If the study of metacognition in the field of science education is to continue to mature and have a meaningful impact on students' learning and teachers' pedagogies so that improvements in students' learning can occur, we should acknowledge different viewpoints and begin to try to build a unified yet eclectic theory that attends to what metacognition is, how we can assess students' metacognition and how we can enhance and develop metacognition within and across everyday science learning environments. Such a theory must be able to guide reform so that metacognition is more visible and prioritised in science education reforms.

Fundamental Issues: Definitions and Premises

Two notions that should be challenged at the outset are that all metacognition is 'good' and that only one form or variety of metacognition is 'good'. These are dangerous premises because the social and educational environments within which students live and learn largely shape their metacognition. If we consider that metacognition should facilitate students' achievement of desired learning outcomes within their life contexts, then the metacognition that they develop and employ should be adaptive for those contexts. Therefore, we should consider students' metacognition as a consequence of the psychosocial environments within which they learn to reason rather than as some innate ability or process. What is adaptive for one environment might not necessarily be adaptive for another. Therefore, deficit or one-size-fits-all models of metacognition should be treated with some caution because it could be potentially dangerous, if not unreasonable, to assume that we will ever be able to construct a model of the ideal metacognitive student. This is because what is valued as effective thinking and thinking processes, and as appropriate metacognition, can vary across cultures as was noted by Gregory Thomas (2006).

Despite this caveat, it is known that metacognition is malleable to classroom interventions that are carefully implemented and that changing classroom environments to become more metacognitively oriented is a key to developing and enhancing students' metacognition. However, all efforts to develop and enhance students' metacognition take place within sociocultural contexts whose influence cannot be understated. Examples of successful interventions are considered later in this chapter. It is also known that there are student barriers that confront those who try to implement appropriate and well-reasoned interventions. However, these barriers often are not considered or are understated in most research into metacognition, especially in clinical and laboratory studies. One reason for this relates to the difficulty still experienced by scholars collectively in developing a precise and agreed-upon definition of metacognition.

A range of definitions continues to appear across the educational literature. Douglas Hacker (1998) and Gregory Thomas (2009) have suggested that the diversity of definitions might reflect different regional orientations and the past and present contexts of those working in this field. Further, as different schools of inquiry into metacognition have developed and as graduate students from different countries have increasingly come to study metacognition with established scholars, graduate students have taken back to their countries of origin the conceptual frameworks that framed their studies. The surge in the availability of literature regarding metacognition since the expansion of the information highway has brought metacognition to the attention of an increasing number of scholars worldwide. Therefore, it is no surprise that the various definitions of metacognition have spread as the technology has afforded increased information transfer, and as the notion of academic scholarship throughout the world has increasingly been constructed around research and publications that rely on existing literature as the source of theoretical frameworks. Finally, a further source of definitional unease arises from considering in the relationship between metacognition and self-regulated learning. Marcel Veenman et al. (2006) note that, according to some scholars, metacognition is subordinate to self-regulated learning, whilst others suggest that it has a superordinate relationship. Others contend that they are part of the same construct. Irrespective of the precise relationship, research related to both constructs is concerned with understanding and improving students' learning processes and outcomes and deserves attention. Interestingly, a review of the literature suggests that more research in science education has been conducted under the banner of metacognition than that of self-regulation.

Obviously there exists a multiplicity of opinions about exactly what metacognition is and this issue is unlikely to be easily or quickly resolved. However, amidst this uncertainty, there have emerged some understandings that seem to be more and increasingly shared than contested. These include acknowledging the more modern-day origins of the concept and the seminal work of John Flavell (1976, 1979) and Ann Brown (1978). Flavell (1976) considered metacognition to be 'one's knowledge concerning one's own cognitive process and products or anything related to them' (p. 232). Flavell (1979) further highlighted the importance of and distinction between metacognitive knowledge and metacognitive experiences. Metacognitive experiences are 'any conscious or affective enterprises that accompany or pertain to any intellectual enterprise'. These two constructs, metacognitive knowledge and experiences, are important for both methodological and pedagogical reasons discussed later in this chapter. Metacognitive knowledge encompasses 'knowledge or beliefs about what factors or variables act and interact in what ways to affect the course and outcome of cognitive exercises' and is not 'fundamentally different from other knowledge stored in long-term memory' (Flavell 1979, p. 907). Metacognitive knowledge can be further categorised as declarative, procedural or conditional. Recently, the nature of metacognitive knowledge has again been considered and finer categorisations of metacognitive knowledge have taken place. These categorisations relate specific metacognitive knowledge to the cognition with which it is aligned. For example Nelja Yürük (2005) refers to metaconceptual metacognitive knowledge as that metacognitive knowledge that relates directly to control, monitoring and evaluation of the cognitive processes that individuals employ to develop conceptual understanding. David Anderson et al. (2009) have identified metasocial metacognitive knowledge as an individual's metacognitive knowledge that relates to social interactions and relationships and how these influence cognition, learning processes and task behaviours. It is likely that further sub-categorisations of metacognitive knowledge using their aforementioned criterion will be forthcoming as researchers continue to consider more finely how elements of metacognitive knowledge relate to specific cognitive processes.

Whilst a uniform theory of metacognition is not yet agreed upon, there has been progress made in developing shared understanding. If we deconstruct existing definitions, it seems that their intent is often much the same. Further, elements such as metacognitive knowledge, regulation/control and monitoring/awareness are common between many of the definitions. Also emerging from the uncertainty as to what metacognition is, but not to the same extent as the previously mentioned definitional issue, is that metacognition refers to a conscious, reflected-upon and deliberate form of thinking that can be reported upon by individuals (e.g. Nelson 1996; Hennessey 2003). This perspective has significant implications for how research can be conducted in relation to metacognition and, consequently, is still the subject of some debate. Implications of this view are discussed further in the section that follows.

Methodological Considerations

Also highly contested in the field of metacognition studies is how best to collect data that provide confirming and disconfirming evidence for the existence, quality and extent of individuals' and groups' metacognition. As Richard White (1998) noted, because metacognition is a mental activity, 'its presence can be inferred, but not observed directly' (p. 1211). Therefore, because all measures of metacognition involve different degrees of inference, a source of contention is the extent to which different scholars agree to accept higher or lower degrees of inference in relation to data collected and its analysis and interpretation. Often, as pointed out by Anderson et al. (2009), researchers' approaches to investigating metacognition might be understood as influenced by a combination of the research paradigm with which they are aligned and the definition/s of metacognition that they employ. Two categories of research orientations in relation to metacognition emerged from the review of David Anderson and colleagues. The first of these, reflecting a *positivist-decontextualist* paradigm, is most often characterised by attempts to ignore or at least minimise the influence of important learner and/or context variables such as students' motives, the details and nature of the subject matter and learning environment under consideration, the cognitive and processing demands related to learning specific subject matter, and the effects of any intervention on the psychosocial nature of the learning environment itself. According to those subscribing to this orientation, these matters are considered at best as unwanted errors, a nuisance and of minimal interest. Hence, they tend to be largely, if not completely, ignored. Further, researchers aligned in such a way often use two or fewer methods within their research designs to reveal and/or understand metacognition and pay little attention to the context within which that data are collected. Such researchers are often more likely to have been trained in the traditions of psychology and rarely do their publications find their way into mainstream science education journals.

Researchers more aligned with the second of these orientations, which reflects a *relativist-contextualist* paradigm, regard contextual factors as highly relevant to metacognitive performance, development and enhancement. Their position is consistent with acknowledging the importance of the psychosocial constitution of students' learning environments in influencing students' metacognition. In other words, the ecology of the learning environment within which the learner is embedded is seen as vitally important to understanding the learner and the learner's metacognition. Studies reflecting this paradigm are typically interpretivist in nature and often employ qualitative or mixed methods. In science education, studies reflecting this paradigm have become most common in the literature. This in large part could be because of science educators continuing to be highly interested in the application of emerging theoretical perspectives from the field of psychology in understanding and attempting to enhance students' science learning. Further, those undertaking these studies are typically interested in providing vicarious experiences regarding the educational contexts within which the studies are undertaken. Examples of studies in science education reflecting this paradigm include Gregory Thomas and Campbell McRobbie (2001), Anat Zohar (2004), Jenni Case and Richard Gunstone (2006) and Anderson et al. (2009). Of course, as pointed out by John Dunlosky et al. (2009), this position can be problematic for those seeking to develop a generalised theory of metacognition and employ representative design principles but, to some extent, it attends to their contention that 'to obtain generalizability across environments, education researchers should begin by describing the environment to which they want their outcomes and conclusions to generalize'.

Irrespective of the paradigm employed within science education research into metacognition, there is a need to be aware of fundamental methodological considerations that extend beyond the aforementioned paradigm issue. Investigations of metacognition rely to a large extent on self-reports and, consequently, findings from studies relying on such measures have the potential to be queried. For example, verbal reports have been criticised on the grounds that (a) individuals might not be able to articulate the functioning of their own minds (Nisbett and Wilson 1977), (b) automated, recurrent processes can become routinised to the point that they are no longer distinguishable or reportable (Ericsson and Simon 1980), (c) interviewees can tell more than they know (Nisbett and Wilson 1977) and/or (d) interviewees could lack the verbal facility necessary to communicate their thoughts accurately (Cavanagh and Perlmutter 1982). Despite these potential shortcomings, verbal and self-reports have a long history in research into metacognition in cognitive psychology and science education, and therefore it is unlikely that their use will decline, at least in the near future. Douglas Hacker and John Dunlosky (2003) provided an overview of the three types of verbal reports (concurrent, retrospective and prospective) and they explored their relationships with three levels of verbalisations. They argued that Level 3 (concurrent verbalisation), in which students are asked to convey information 'that is currently in a verbal or nonverbal form and the additional thinking that is potentially contributing to that information' (p. 75), holds great potential for exploring and enhancing students' metacognition in relation to their problem solving. Their view coalesces with that of Marcel Veenman and colleagues (2006) who distinguish between off-line and online methods. Off-line methods relate to those presented either before or after task performance, whilst online methods are those conducted concurrently during task performance.

Whilst Veenman and colleagues (2006) acknowledge that all methods have pros and cons, they contend that (a) online methods appear to be more predictive of students' learning performances and (b) scores on questionnaires 'hardly correspond to actual behavioral measures during task performance' (p. 9). They argue further that there is a need for research with multi-method designs and, in so doing, echo White's (1998) view that more than one method or test is necessary to evaluate or measure metacognition and that 'good research on metacognition involves a battery of diverse but supportive measures' (p. 1211). Fortunately, exemplar science education studies by Thomas and McRobbie (2001), Zohar (2004), Peters (2007) and Anderson et al. (2009) employed multi-methods designs that are available for critique. Even though the findings from such studies might be debated in relation to the dependability and/or reliability of the corpus of methods employed, these studies are evidence of the substantial evolution in the methodologies used in investigating metacognition in science education.

Perhaps we need to consider seriously that conducting any research into metacognition (which involves seeking data from research subjects) is itself a form of intervention that has the potential to provide a metacognitive experience for the student. The degree of inference that we are prepared to accept is a key to how future research in metacognition will be undertaken and what value will be assigned to the findings of that research. The extent to which we agree on the transferability of findings from one context to another depends on the breadth and depth of the description of the research context that accompanies and frames those findings.

Intervention Considerations: How Best Can We Facilitate Metacognitive Development in Science Education?

As previously mentioned, a major focus of research in science education is the improvement of students' learning of science concepts. Alongside this focus is increased attention to developing students' learning processes and their metacognition as an integral priority. All attempts to develop and enhance students' metacognition hinge on researchers' and teachers' views on what metacognition is and what should be prioritised in science learning environments. Further, as will be explained, it is essential to acknowledge the role that students' existing metacognition, including their beliefs about the nature of learning and learning processes, plays in setting and influencing the context within which interventions occur. The position taken in this chapter is that the development and enhancement of students' metacognition should be a high priority for science teachers and science teacher educators. This section of the chapter explores how students' metacognition can be developed and enhanced and the conditions under which this might best be facilitated.

Developing Metacognition Using Metacognitive Activities

A review of the literature suggests that interventions that seek to develop and enhance students' metacognition can be categorised as one of two types. The first of these is characterised by a focus on the use of heuristics and learning strategies that have commonly become known as metacognitive activities. The more recent studies by Lisa Blank (2000), Bette Davidowitz and Marissa Rollnick (2003), Petros Georghiades (2006) and Lindsay Connor (2007) are studies that exemplify this approach. Notably, a major element of the Project for Enhancing Effective Learning (PEEL) (Baird and Mitchell 1986; Baird and Northfield 1992) was also developed around the principle that engaging students in activities that help them to consider subject material, its organisation and its manipulation in ways they had previously not considered can be metacognitive experiences that act as stimuli for the enhancement of students' metacognition. In other words, by changing the learning environment and providing new and alternative activities, it is possible to facilitate the development of students' metacognition.

This approach is appealing for a number of reasons. First, students are introduced to the new activities in the context of learning science concepts and skills. As Richard Gunstone (1994) has suggested, it is important to embed training in metacognition within the real-world demands of students' science learning. After all, because students come to science classes to learn science, embedding metacognitive training within everyday science tuition increases the chance that students will be motivated to attend to the activities that are suggested to them, thereby also increasing the chances that they will reflect on the use of these activities for learning science. Second, as suggested by Marcel Veenman and colleagues (2006) 'the vast majority of students spontaneously pick up metacognitive knowledge to a certain extent from their parents, their peers, and especially their teachers' (p. 9). Therefore, we might reasonably expect that students would spontaneously develop metacognitive knowledge to some extent from the embedding of metacognitive activities within everyday classroom instruction, and indeed such development is reported in these studies. Petros Georghiades (2004) has argued further that this way of developing metacognition is appropriate because metacognitive skills require awakening via the use of appropriate stimuli and because metacognition 'is not something to be "taught" to the learner in an "outside-in" process, but rather it is a skill that can be helped to develop in an "inside-out" manner' (p. 369).

Despite support for this approach and its obvious appeal to the majority of science education researchers investigating metacognition, a number of issues can be raised in relation to its appropriateness for developing metacognition. The question that might be asked is: 'If there is no conscious reflection by the individual in relation to the new demands of the learning environment for the value of his or her learning, then has metacognition been engaged and/or developed?' As previously noted, developing and enhancing students' metacognition requires that they undertake conscious reflection regarding the efficacy of the learning processes, activities and strategies that they employ or are asked to employ. Previously in this chapter the notion of metacognition was confined to those thinking processes that individuals consciously monitor, control and are aware of. Once again the distinction between metacognition and cognition needs to be acknowledged and considered in relation to this 'metacognitive activities' approach.

It could be argued that, because the use of heuristics (such as concept maps, reading charts, Venn diagrams, theory-evidence coordination rubrics, inquiry flowcharts and any other means of assisting students to develop and represent their understandings of science and its processes) target cognitive processes predominantly, it is only through conscious reflection on the use of these heuristics and frameworks that metacognition develops. Therefore, the use of this approach should be coupled with opportunities for students to reflect consciously on the metacognitive experience that accompanies their use of the strategies/heuristics. Unfortunately, the evidence that this happens frequently enough in science learning environments is not strong. Because the priority within those environments relates to the learning of the science itself, the development and enhancement of students' metacognition is seen as a secondary objective at best. This is not surprising given the strong subject-oriented background of most science teachers and their strong belief in the importance of developing students' conceptual science knowledge, scientific literacy and understanding and use of methods associated with scientific inquiry. Teacher education courses and professional development activities should make it obvious to prospective and practising teachers that there is a need for them to set aside time so that students can reflect on their learning processes, how they might be improved and what it might mean to be an effective science learner. If this does not occur, then the true potential of this approach to developing metacognition is never likely to be fulfilled.

Developing Metacognition Through Metacognitive Conflict

An alternative to the metacognitive strategies approach is reported by Thomas (Thomas 1999; Thomas and McRobbie 2001). This approach is consistent with the suggestions of Greg Schraw (1998) that it is appropriate to consider metacognitive knowledge as multidimensional, domain-general and teachable. This type of approach involves engaging and challenging students in considering what learning (science) is. Within the context of an upper secondary high school chemistry class, Thomas and McRobbie (2001) challenged students through the use of the metaphor 'learning is constructing' to consider what learning chemistry might 'look' like and therefore what mental processes might be engaged to facilitate their chemistry learning with increased understanding. The decision to employ metaphor was based on the notion that, consistent with constructivist epistemology, new ideas in any domain are constructed via ideas that one already possesses, language is a key element that mediates the thinking processes of students, and learners subscribe to their conceptual structures because they are viable for them individually, not because they are absolute. By working backwards from what students already believed effective chemistry and science learning to be, and also by challenging students to consider alternative and previously-unconsidered conceptions of chemistry and science learning, Thomas and McRobbie initiated metacognitive conflict in students' minds.

Metacognitive conflict can be considered analogous to cognitive conflict, which is a notion familiar to many science educators. It involves placing students in situations in which their existing conceptual frameworks related to science concepts are challenged and in which they have to consider new conceptions of science phenomena with reference to those already existing frameworks. Indeed, conceptual change and how to facilitate it in science classrooms have been the major foci of science education research over the past three decades because findings regarding students' alternative conceptions began to appear in the literature. If this framework for conceptual change is to be transposed onto students' conceptions and beliefs regarding what learning (science) is, how it can best be undertaken and how it can best be evaluated, then it follows that the same conditions are required to facilitate conceptual change in science concepts and students' metacognition (especially their metacognitive knowledge that consists of declarative, procedural and conditional elements). Metacognitive experiences therefore become those conscious experiences occurring when students are asked to consider the intelligibility and plausibility of conceptions of learning science, are encouraged to employ processes consistent with those new conceptions and then provided with opportunities to consider the fruitfulness of adopting new conceptions and associated processes/strategies for their ongoing science learning. Obviously, those students who decide to adopt such conceptions and related strategies/processes are making a conscious choice to do so (Thomas, 1999).

It is necessary for teachers adopting this approach to (a) be highly metacognitive, (b) have a thorough understanding of the nature and structure of the subject area and material that they are teaching and that is to be learned, (c) be able to converse with students about the cognitive processes and strategies that can be employed to bring about the conceptual understanding of the subject matter and (d) be able to model those cognitive processes and strategies for students to emulate (i.e. to act as cognitive and metacognitive role models). It is also necessary for them to be able to develop classroom environments that are metacognitively oriented as described by Gregory Thomas (2003). Metacognitively oriented science classrooms are characterised by: appropriate levels of metacognitive demands on students; student-student discourse and student-teacher discourse regarding the learning that occurs and the cognitive processes and activities that enable successful learning; students being able to query the activities in which they are asked to engage and having adequate levels of control and choice in relation to those activities; students being encouraged and supported by the teacher to improve how they learn science; and high levels of emotional support and trust between the teacher and students.

These conditions are often not found to coexist in many science classrooms, with most science learning environments continuing to be characterised by didactic teacher exposition, the teacher being an authority figure, and little discussion of possible alternative environments to those already existing and themselves largely determined by teachers, and existing social and systemic norms and expectations. This perspective should not come as too much of a surprise to those who are familiar with the day-to-day operations of science classrooms, teacher pedagogies, the enactment of mandated curricula, and the insidious creep of standardised testing into educational thought and practice. Further, as noted by Petros Georghiades (2004, p. 379), 'the notion of metacognition is largely unknown to the average science teacher'. This presents a highly problematic situation if students' metacognition is to receive increased attention that it deserves. Georghiades goes on to suggest that even those who are familiar with the concept of metacognition lack the resources or authority to facilitate metacognition in their teaching. It could reasonably be argued that time is the only resource that might not easily be available to teachers who adopt this second approach. It could also be argued that teacher education programmes should graduate science teachers who possess the characteristics identified above. As explained in the next section, more attention should be given to understanding, developing and enhancing teacher metacognition in science education.

Emerging Areas in the Study of Metacognition in Science Education

Two areas particularly require further research into metacognition in science education: metacognition in informal science learning environments; and science teacher metacognition. These areas also have potential for improving students' metacognition and learning and for increasing collaboration between scholars and science educators from across disciplines and locations. They are discussed briefly below.

Metacognition in Informal Science Learning Environments

David Anderson et al. (2003) noted that studies that focus on students' metacognition were absent from the research on learning on students' science learning environments. They proposed that increased understanding in this area had the potential to enhance students' learning and contribute to educational research in informal settings. The Metacognition and Reflective Inquiry (MRI) Collaborative, a multi-year, multi-case, research study that investigated the elusive nature and character of high school students' metacognition across formal and informal science learning contexts, followed from these realisations and involved a series of interpretive, layered hermeneutic case studies conducted over three years. Studies emanating from the MRI (e.g. Anderson and Nashon 2007) have shed light on students' metacognition in informal science learning settings, but further research is necessary to add to these emergent findings. Given the increased attention being given to science learning in informal contexts, it is anticipated that this line of metacognition research will continue for some time.

Science Teacher Metacognition

As previously noted, metacognition development requires that science teachers are themselves metacognitive and able to communicate with students regarding the benefits of particular ways of thinking about learning science and how it might best be facilitated. However, the extent to which science teachers are themselves metacognitive is not altogether clear. Anat Zohar (1999, 2004) highlighted the importance of teachers' metacognitive knowledge and the difficulty that teachers have in changing from traditional instruction to that which focuses on the teaching of higher-order thinking. She also noted the difficulty that teachers have in articulating their thinking patterns during problem solving and concluded that adequate and appropriate teacher metacognitive declarative knowledge is essential for the teaching of higher-order thinking. In a similar vein, Mary Leou et al. (2006) found that challenging teachers regarding their own metacognitive knowledge in relation to higher-order thinking processes is important in facilitating transfer of that knowledge into their own pedagogical practices. More research on teacher metacognition might enable increased effectiveness of professional development activities that aim to help teachers to develop higher-order thinking and metacognition in science learning environments.

Looking to the Future: Revisiting White's 'Decisions and Problems'

Richard White (1998) highlighted the need, in research on metacognition, to study subject-rich contexts, for studies to be long term, and to attend to scale, focus and variations within extended studies. He also drew attention to issues in recording and describing interventions and in measuring and reporting the effects of interventions. Whereas this chapter has provided evidence that there have been advances within and beyond science education in the study of metacognition and how to facilitate its development and enhancement, the concerns raised by White persist and still deserve earnest concerted attention. It should be added that seemingly ever-increasing ethical requirements for conducting research, especially in school contexts within which students that have not yet reached the age at which they can give informed consent, also have the potential to influence the type and length of research conducted, the questions asked, the means of data collection, and the nature and details of the interventions attempted.

The eventual aim of studying and facilitating metacognition in science education environments is to lead to improved individuals' learning within and beyond science education. Dialogue regarding the issues facing the study of metacognition by those working in the field is vibrant and ongoing. As stated previously, the aim of this chapter has been to stimulate ongoing discussion and debate within the science education community by addressing a range of perspectives on metacognition, some of which are more contested than others. This was chosen in preference to taking a conservative, middle-ground approach to the issues. It is only through such dialogue and willingness to engage in debate that we can continue moving forward in the study of metacognition in the field of science education.

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Chapter 12
Learning From and Through Representations in Science

Bruce Waldrip and Vaughan Prain

There is now broad agreement that the representational tools through which we think influence 'how we think and what we can think about' (Eisner 1997, p. 349). In learning to think and act scientifically, students therefore need to know how to integrate the multimodal discourses of science for which different modes serve different purposes in reasoning, recording scientific inquiry and producing knowledge. Mathematical, verbal and graphic modes are used individually and in coordinated ways to represent knowledge claims in this subject, with more recent technology-mediated representations of science consistent with, rather than a deviation from, this evolution of science as a discipline. In this chapter, we review current approaches to researching how students might be supported to acquire this disciplinary literacy, identify ongoing challenges to these approaches and discuss future agendas for this research.

Research Agendas About Learning Science Literacy

Over the last 15 years, science education research into student acquisition of this disciplinary literacy – variously defined as 'metarepresentational competence' (diSessa 2004, p. 293), as the metacognitive skill of 'visualization' (Gilbert 2005, p. 9), or more broadly as the capacity to construct appropriate meanings from and through science representations – has had two major foci. One perspective has entailed researcher analysis and construction of representations as a basis for investigating factors affecting

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student learning from interactions with these representations (see Ainsworth 1999, 2006, 2008a, b, c; Gee 2004; Gilbert et al. 2008; Ginns 2005; Jewitt 2007; Jewitt et al. 2001; Rahm 2004; Unsworth 2001, 2006; Van der Meij and de Jong 2006). This research has often been driven by the perceived affordances of new multimedia for enhancing student learning. The second perspective has focused predominantly on student-generated representations, incorporating both new and old technologies, as a strategy to promote science literacy (Cox 1999; Greeno and Hall 1997; Hand 2007; Hayes et al. 1994; Prain 2006, 2009; Prain and Hand 1996; Ritchie et al. 2008; diSessa 2004; Treagust 1995; Tytler et al. 2006; Waldrip and Prain 2006).

Both perspectives have been guided by recent research in cognitive science, semiotics and sociocultural theories, and have aimed to identify the nature and complexity of learning tasks in this domain, as well as contextual factors affecting this learning, including classroom teaching and learning strategies for different cohorts of learners. Both perspectives are necessarily symbiotic, in that students clearly need to know how to interpret as well as construct representations in this domain to achieve science literacy, as noted by Stephen Norris and Linda Phillips (2003). However, researchers have tended to focus predominantly on only one area, perhaps partly because of the complexity and novelty of various emerging representational options, given continuous new developments in multimedia, but also because of contrasting traditions and assumptions within and across these research agendas regarding how this literacy learning is best facilitated.

Learning Through Interpreting Representations

Within this general orientation, and drawing mainly on cognitive science perspectives, Shaaron Ainsworth (1999) asserted that, in order to learn from engaging with multiple representations of science concepts, students need to be able to (a) understand the codes and signifiers in a representation, (b) understand the links between the representation and the target concept or process, (c) translate key features of the concept across representations and (d) know which features to emphasise in designing their own representations. In this context, 'translation' means being able to recognise conceptual links between representations or invariant conceptual features across representations. These learning processes are also consistent with Allan Paivio's (1986) theoretical account of the function and value of multiple coding in learning.

In focusing on the number, type, style and sequence of representations to support student learning, researchers predominantly from cognitive science perspectives have identified a range of factors impacting on student learning. These include the need for effective design in representations, with clear links between words and images and excluding extraneous material (Kozma 2003; Mayer 2003; Moreno and Valdez 2005; Schnotz and Lowe 2003). Robert Kozma (2003, p. 226) found that 'symbolic environments' supplemented with classroom laboratory activities can effectively support science learning. Other researchers have identified the crucial role of student background knowledge in effective learning through multimedia environments (Ainsworth 2008c; Cook 2006; Schnotz and Bannert 2003; Seufert

2003), as well as the value of student self-explanation about representations (Ainsworth and Burcham 2007). In other words, students need to reflect on the clarity and adequacy of the meanings that they are deriving from engagement with these representations if effective conceptual understandings are to be achieved. Whilst some of this research has focused on clinical trials of representational options outside mainstream classroom contexts, other researchers such as Carey Jewitt et al. (2001), Jewitt (2007) and Len Unsworth (2001) drew on semiotic frameworks to focus on diverse classroom practices to facilitate student interpretation of scientific representations, including technical vocabulary, diagrams, tables, flowcharts and graphs in both traditional and web-based multimedia texts. Researchers have also investigated the extent to which dynamic representations, such as spoken voice, animation and dynamic graphs, enhance or impede interpretation of represented information when contrasted with static representations (Ainsworth 2008c; Lowe 2004; Lowe and Schnotz 2008). Shaaron Ainsworth (2008c) noted that student viewing of animations often failed to enhance metacognitive understanding, and that their transient nature also posed problems for student perceptual processing and memory.

Another area of focus is the extent to which interpretive constraint in a representation, such as graphic simplicity, helps or hinders student understanding, and under what conditions (Ainsworth 2008a, b, c; Eilam and Poyas 2008). Ainsworth (2008c) claimed that too often students' simultaneous exposure to multiple representations make learning more difficult, and that students needed peer and teacher support in an effectively structured learning environment. In evaluating multimedia environments, Ainsworth (2008b) noted that, whilst experimental designs are useful for analysing some effects, a more extended focus on the processes through which students coordinate representations could yield important insights into an effective environment. Other researchers have investigated the challenges for students in developing conceptual understanding across microlevel and macrolevel representations of the same topic (Pilot et al. 2009).

As noted by Ainsworth (2008a), recent research on student interpretation of multiple representations has revealed both the complexity of factors affecting this learning and their interdependence. For example, increasing the options in relation to interactivity between a student and an expert representation might increase motivation (for some learners), but also entail increased cognitive demands. Ainsworth (2008a, p. 62) also pointed out that, whilst the dominant cognitive science orientation to this research has identified potential cognitive challenges and learning gains, this perspective has tended to ignore 'expressive, perceptual, affective, strategic, metacognitive and rhetorical' aspects of students' responses and understandings, which are all critical factors in how students engage with representations, and learn from this interaction. There is also a need for more research focus on the influence of particular teacher practices, classroom contexts and routines on different learners. To address this complexity of influences, Ainsworth (2008a) advocated the value of multimethod approaches and multifocus research that identifies how the interplay of diverse factors affects different student cohorts. Rolf Ploetzner and colleagues (2008), Michelle Cook (2006), Jannet Van Drie and colleagues (2005) and Erica De Vries (2005), and many others, acknowledge that students' interactions with multiple representations require considerable supplementary support to ensure enhanced learning.

In summary, research on student learning from engagement with, and interpretation of, representations remains in an emergent phase because of (a) the rate of change in representational options in new technologies for conducting and reporting scientific activity and for designing teaching and learning multimedia resources in science, (b) the growing recognition of the considerable complexity of factors that influence student understanding, engagement and learning in this field and (c) the increased acceptance of the need for multimethod research that includes analysis of the effects of different classroom and out-of-school settings and practices on student learning. There is growing acceptance that this research requires a matching conceptual complexity in research design and focus in order to address the intricate ecology of learning opportunities and desirable learning outcomes in this field.

Learning Through Student-Generated Representation

Research on this learning pathway has received less attention than analysis of students' responses to authorised representations, perhaps because it does not fit easily into traditional assumptions about effective student induction into disciplinary norms through exposure to authorised representations, and because it makes considerable demands on teachers' conceptual science knowledge and teaching skills in building bridges between students' representations and scientific discourse. However, there is a range of theoretical justifications for this approach as well as a growing body of evidence to support the value of student-generated representations in promoting learning.

Rationale for This Approach

This approach has been justified in terms of theories drawn from semiotics, sociocultural theories of science as a practice of knowledge production, recent research in cognitive science, and pedagogical principles about conditions for effective learning. From a semiotic perspective, students' diverse interpretive capacities can be understood as representational competence (diSessa 2004), and as crucial to science learning in primary and secondary school. As noted by Jay Lemke (2004), drawing on Charles Peirce (1931–1958), representational competence is about knowing how to interpret and construct links between an object, its representation and its meaning. A representation becomes a sign when it signifies something (a key idea or explanation) about the object (or referent) to someone (the learner). Meaning-making practices in school subjects, including science, can be understood in terms of this triadic account of the necessary components of meaning making. In this model, when applied to science, distinctions can be made between a representation in a sign (e.g. arrows in diagrammatic accounts of force), the interpretation or sense made of this sign (the scientific idea of force) and its referent (the phenomena to which both the interpretation and signifier refer, such as the specific operation of force on objects in the world). This implies that, for learners to understand or explain concepts in science, they must use their current cognitive and representational resources to learn new concepts at the same time as when they are learning how to represent them. In this way, student representations and their revision can function variously as exploratory tools for initial thinking, scaffolding for building understanding, and as records of new thinking and reasoning, depending on the purpose or purposes of the representation. Michael Ford (2008) argued that, in this approach, consistent with science as a practice of knowledge production through claim and counterclaim, a key role of the teacher is to build and support communities that explore new knowledge claims through representation.

Recent research in cognitive science also provides some support for a focus on student-generated representation as a strategy for learning the literacies of science (Barsalou 1999; Klein 2006; Schwartz and Heiser 2006). This research provides a rich picture of diverse factors that influence effective learning generally, and science in particular, with conceptual knowledge being seen more as implicit, perceptual, concrete, and variable across contexts, rather than as primarily propositional, abstract and decontextualised (Barsalou 1999). This research recognises the fundamental role in learning of context, perception, motor actions, identity, feelings, embodiment, analogy, metaphor and pattern completion. This implies that students are more likely to learn science concepts effectively when they can coordinate perception and actions, such as when attempting to represent teacher-guided explanations or claims about a topic. Schwartz and Heiser (2006) noted that students can visualise and imagine situations and predict outcomes accurately even if they cannot verbalise, because perceptual resources and contextual clues provide the bases for this thinking. Perry Klein (2006) and Russell Tytler et al. (2006) and others asserted that students are more likely to remember appropriate meanings for science experiences when they can also connect them to their personal histories, to meaningful everyday contexts, to representational challenges and to an identity that includes acting scientifically. The implications of this research for representational work are that students need to be supported to (a) map perceptual links between science activities and their 2D and 3D representation and (b) connect representations with meaningful everyday experiences and interests.

Apart from these theoretical justifications, there are strong pedagogical reasons for giving students opportunities to construct their own representations of developing understandings of science topics. Ronald Giere and Barton Moffatt (2003) make this point through a comparison with learning long-multiplication in mathematics. They note that many people learn to multiply large numbers, a task that would be difficult to do mentally, by using a representational framework of written numbers, symbols and manipulations:

$$
\begin{array}{r}
\hline
456 \\
\times\, 789 \\
\hline
4{,}104 \\
36{,}480 \\
319{,}200 \\
\hline
359{,}784 \\
\hline
\end{array}
$$

This representation functions as a thinking tool or scaffold during the manipulation, and then becomes an artefact of this thinking, shifting from a 'live' representation during the process of constructing an answer to a 'dormant' representation, unless used for more re-interpretive thinking. A mathematics teacher would not consider students 'mathematically competent' in long multiplication if they had never practised this computation and, instead, had just observed the constructed representation and learned to recall it by rote. For Ronald Giere and Barton Moffatt (2003), the same idea applies in science learning, for which students should learn how to use representations as thinking tools for predicting, understanding and making claims, rather than for memorising 'correct' representations for knowledge display. Supporting this view, Andrea diSessa (2004, p. 299) asserted that students bring to learning in science some understanding of the need for 'conciseness, completeness and precision' in representing ideas, and that 'good students manage to learn scientific representations in school partly because they can almost reinvent them for themselves'. This implies that students are likely to learn more effectively in science when they see the aptness of representational conventions used in this subject, and also when they recognise the persuasive nature of particular scientific explanations.

Classroom Research Based on this Approach

Drawing on these different theoretical orientations, various researchers have investigated the learning potential of student-generated representations (Cox 1999; Danish and Enyedy 2006; Greeno and Hall 1997; Hand 2007; Hayes et al. 1994; Prain 2009; Prain and Hand 1996; Ritchie et al. 2008; Treagust 1995; Tytler et al. 2006; Waldrip et al. 2006). This approach involves students in using a more diversified range of representations, both formal and informal, to engage with the practices and intent of scientific investigation. The approach assumes that mobilising students' current representational capacities is crucial to achieving effective engagement with, and learning of, the literacies of science. In advocating text diversification, these researchers accept that students need to demonstrate a capacity to use accurately the current vocabulary and multimodal representations of science discourse. However, they argue that there are motivational gains and enhanced learning opportunities when students engage in a cycle of planning and guided revision of different text types, which involves a strong emphasis on clarification of claims in science and their justification for both self and others. James Greeno and Roger Hall (1997) pointed out that, if students only participate in teacher-designed activities, then various learning opportunities are constrained. They argued that student construction and interpretation of representations enabled students to see these representations as important tools for constructing and communicating understanding that is adaptable to the purpose at hand, and that students could be engaged in discussing the properties of representations, including their strengths and limitations.

Hand (2007) reported strong learning gains for students when they constructed a modified laboratory report for which they were expected to make and justify claims.

Dorothy Hayes et al. (1994) suggested that student-constructed drawings had the potential to develop skills, knowledge and understanding, and that drawing was an underutilised tool in learning and recording thinking, which is in agreement with Margaret Brooks (2005) and Jane Dove et al. (1999). According to Lilian Katz (1998) and Paula Goolkasian and Paul Foos (2002), drawing helped students' reflection about their learning, observations, activity and thinking, as well as assisting in conceptual development. In investigating Grade 4 students' drawing of optics, Yongcheng Gan and Marlene Scardamalia (2008) claimed that student-generated drawings promoted deeper understanding of content, improvement of ideas and conceptual change, problem-solving and theory-building and modelling. Stephen Ritchie and colleagues (2008) reported high levels of students' interest when they wrote an extended ecological mystery story that combined an illustrated narrative with factual knowledge relevant to the story. The researchers also asserted that student learning was enhanced through this combination of extended field work and a team-authored narrative supported by strategic teacher guidance. Other researchers, such as Janice Gobert and John Clement (1999) and Peggy van Meter (2001), have claimed that some modes can be more supportive of student learning than others, noting that students can 'draw to learn' effectively when the visual media affords 'specific advantages over the textual media' (Gobert and Clement 1999, pp. 49–50). According to Andrea diSessa (2004, p. 298), 'students start with a rich pool of representational competence' based on their past experiences with interpreting visual texts, and are 'strikingly good at … designing representations'. He considered therefore that 'rich and engaging classroom activities are relatively easy to foster' (p. 298) and are highly motivating for learners.

These studies indicated that representations in science serve many different purposes. Whilst these purposes are conventional and functional for producing knowledge in the science community, they can also serve learning purposes for students in the science classroom. In this way, representations can be used as tools for initial, speculative thinking, as in constructing a diagram or model to imagine how a process might work, or find a possible explanation, or see if a verbal explanation makes sense when re-represented in 2D or 3D. They can be used to: record precise observations; identify the distribution of types; classify examples into categories; identify and explain key causes; integrate different ideas; contextualise the part to the whole; identify the inner workings of a machine or object; show key parts; show a sequence or process in time; identify the effects of process, predict outcomes, sort information, clarify ideas, show how a system works, organise findings; explain how parts of a topic are connected and work out reasons for various effects.

These studies have also raised questions about how teachers and students might assess the adequacy of a representation. For Andrea diSessa (2004), this means that students need to understand that a single representation cannot cover all possible purposes or all aspects of a topic. Therefore, they need to learn how to select appropriate representations for addressing particular needs, and be able to judge their effectiveness in achieving particular purposes. He claimed that junior secondary students intuitively have an understanding of the attributes of a good scientific representation, recognising that it must be clear and unambiguous, give minimal but sufficient information and be comprehensive for its purpose. By implication, when students are not clear about these criteria or their rationale of producing clear communication, then these aspects need to be taught explicitly.

Researchers have also sought to identify principles to guide this teaching and learning approach (Carolan et al. 2008; diSessa 2004; Greeno and Hall 1997; Hackling and Prain 2005; Prain 2006; Tytler et al. 2006). Consistent with a conceptual focus in science generally, in this approach, teachers need to be clear at the topic's planning stage about the key concepts or big ideas that students are intended to learn. This focus provides the basis for the teacher to consider which sequence and range of representations, including both teacher- and student-generated ones, are likely to engage learners, develop their understanding, and count as evidence of learning at the topic's end. This approach to science learning is evident in a national professional learning programme, *Primary Connections* (Australian Academy of Science 2007), in which key concepts are emphasised at the start of units of work, and students are expected to develop understanding of these concepts through engaging in guided investigations related to a sequence of representational and re-representational work. Research on the learning outcomes of this programme (Hackling and Prain 2005) revealed that students were more motivated than when using past approaches, and that learning performance was also enhanced. This approach emphasises teacher and student negotiation of the meanings evident in verbal, visual, mathematical and gestural representations in science, with students benefiting from multiple opportunities to explore, engage, elaborate and re-represent ongoing understandings in the same and different representations. However, students still need strong teacher guidance to develop their own representations into the authorised ones of the science community.

In summary, this approach made increased demands on teachers' knowledge base and their teaching and assessment skills, but led to enhanced learning outcomes when implemented effectively. Current research has identified the need for ongoing identification of representational challenges posed by different topics, for further analysis of classroom interactions during which students design and interpret the represented claims that they are making, and for the need for professional learning support for teachers to engage effectively with this approach.

Future Research Agendas

Researchers in both areas acknowledge the complexity of cognitive and other factors that impact upon science literacy learning, whether the focus is predominantly on students interpreting or constructing representations. As suggested in this chapter, there is a need to develop and integrate diverse research methods, to draw on various theoretical frameworks including semiotics, cognitive science, sociocultural perspectives, pedagogical studies and neuroscience and, to address cognitive, strategic and metacognitive dimensions of this learning, as well as expressive, aesthetic, rhetorical and affective aspects of students' responses. These different foci of research will need to be embedded in analysis of the impact of different teaching and learning routines in classrooms and other learning environments. This is not to argue for an overarching synthesis of approaches or a set of universal principles, but rather to suggest that research in this area needs to proceed through both tightly focused studies of representational cases around specific science topics. It is important to recognise the need for diversity of approaches, as well as cross-method, multiframed investigations that establish new insights through research dialogues and build transdisciplinary understanding to guide science literacy learning.

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Chapter 13
The Role of Thought Experiments in Science and Science Learning

A. Lynn Stephens and John J. Clement

In this chapter, we review selected studies of thought experiments used by both experts and students and attempt to develop some useful definitions and conceptual distinctions. We then apply these in an analysis of a classroom episode as an example of the roles thought experiments can play in productive whole class discussions. We are interested in this area because thought experiments are one example of the kinds of creative reasoning of which experts and students appear to be capable under the right conditions.

Review of Selected Studies on Thought Experiments of Science Experts

Certain writers in philosophy of science have been intrigued with thought experiments (TEs) for some time, because if effective, they seem to contradict the spirit of empiricism that dominated the philosophy of science for much of the twentieth century. The idea of obtaining new knowledge from internal mental manipulations alone does not sit comfortably within an empiricist framework.

Authors such as J.R. Brown (1991) and Roy Sorensen (1992) have compiled collections of TEs that were important in the history of science. By now it is widely recognised that at least some TEs in the history of science have been noticeably, if not spectacularly, germane to a scientist's investigation. Famous examples include those used in the Einstein–Bohr debates on quantum mechanics. Nancy Nersessian (1992) has analysed historical records of Maxwell's breakthroughs in electromagnetic

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field theory, finding that a series of thought experiments involving gears and then fluid vortices played a role in his theory formulation.

TEs also have been considered somewhat enigmatic and exotic. The reason for this is captured in what John Clement (2002, p. 32) called the Fundamental Paradox of Thought Experiments, namely, 'How can findings that carry conviction result from a new experiment conducted entirely within the head?' The idea of an experiment (involving observation) being conducted in the head (without observation) appears self-contradictory.

Purposes for Thought Experiments

One line of investigation is to examine the purpose served by thought experiments. Thomas Kuhn (1977) argued that the purpose of a TE is to disconfirm a theory by disclosing a conflict between ones existing concepts and nature. Undoubtedly, TEs are probably most impressive when they act to disconfirm an established theory in science; they then actually seem to be doing something as powerful as a critical experiment or anomaly can do.

On the other hand, Brown (1991) identified several purposes for TEs including constructive as well as destructive (conflict-generating) purposes. He also theorised that a few special TEs could serve both functions. Similarly, Nersessian's (1992) analysis of Maxwell's work hypothesised that a TE could expose conflicts in an existing theory but also point to new constraints that help guide positive modifications of the theory, thus playing both a destructive and constructive role. Interestingly, Athanasios Velentzas et al. (2005) found that textbooks in relativity and quantum mechanics use constructive but not destructive TEs; they feel that the inclusion of destructive TEs could increase student interest.

Clinical Studies

Evidence in historical and philosophical studies has been indirect because these studies have not been able to examine real-time evidence for purposes and mechanisms of TEs as they are being used. Clement (2008, 2009) attempted to collect such evidence by interviewing experts thinking aloud about unfamiliar explanation problems. Think-aloud transcripts are not perfect or complete records of thinking but they do provide considerably more detail than historical papers. He found cyclical sequences of model construction and evaluation, and different TEs being used for model generation (constructive) and model evaluation purposes. He also found that within the evaluation category, TEs could be either disconfirmatory or confirmatory. These studies also confirmed that TEs could be used as a part of the actual thinking process, not just pedagogically.

One problem used was the Spring Problem, which asks whether a first spring would stretch more than a second spring that is identical except with coils twice as

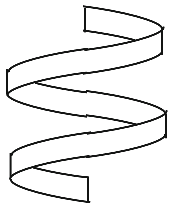


Fig. 13.1 Band spring

wide in diameter. In the simplest possible example of a TE, one subject simply tried to imagine which spring would be harder to pull, saying:

> Episode 1: I'm **going to try to visualize it** to imagine what would happen – my guess would be that it [wider spring] would stretch more – this is a kind of **kinesthetic sense that somehow a bigger spring is looser**….

This is certainly a more primitive experiment than the famous TEs in history of science, and yet it has the basic qualities of imagining the results of an experiment in the head. (The bold type in these episodes denotes imagery indicators, to be discussed later.)

A more creative experiment was generated when this subject engaged the question of whether the deformation in the spring wire is due primarily to bending or to twisting of the wire as the spring stretches. He generated the case of a spring made of a vertically oriented band of material, depicted in Fig. 13.1. The reader might imagine the thin metal strip unwound from a coffee can, reshaped to make a spring 8 cm or so in diameter:

> Episode 2: How about a spring made of something that can't bend. And if you showed that it still behaved like a spring you would be showing that the bend isn't the most important part – **How could I imagine** such a structure? – I'm thinking of something that's made of a band – **we're trying to imagine configurations** that wouldn't bend. Since its cross section is like that [see Fig. 13.1] – it can't bend in the up-down **[indicates up/down directions with hands]** direction like that because it's too tall. But it can easily twist **[gestures as if twisting an object]**.

He inferred that such a spring can still stretch even though it cannot bend, arguing against the theory of bending as necessary for stretching. Here it is more clear that there is a design process leading to a contradiction.

Definitions

Problem in the literature is that there is no consensus on a definition of a TE. Sorensen (1992, p. 205) defines a thought experiment as '(A)n experiment that purports to achieve its aim without the benefit of execution'. However, this shifts much of the burden to the term 'experiment'. Experiment is defined as 'a procedure for answering or raising a question about the relationship between variables by varying one (or more) of them and tracking any response by the other' (p. 186). But as we shall see, some TEs appear to be less formal than a procedure and some appear to envision a single event without systematic variation; alternative definitions may be worth exploring.

The range of TEs in the above episodes – from simple to complex – motivated our formulation of a broad definition and a narrow definition for TEs (Clement 2008), as follows:

> Broad definition: Performing an (untested) thought experiment (in the broad sense) is the act of considering an untested, concrete system (the 'experiment' or case) and attempting to predict aspects of its behavior. Those aspects of behavior must be new and untested in the sense that the subject has not observed them before nor been informed about them.

The word 'untested' is used to rule out cases where the subject simply replays a previously observed event. Still, the above definition is intentionally quite broad and encompasses cases as simple as in the first episode above.

> Narrow definition: Performing an evaluative Gedanken experiment is the act of considering an untested, concrete system designed to help evaluate a scientific concept, model, or theory – and attempting to predict aspects of the system's behavior.

The second band spring episode above had these characteristics since it was designed to test the theory that bending is the source of stretching in springs. In the first episode, the subject was trying to make a prediction only for the specific system and not to test a broader theory.

Possible advantages of these definitions are that they are more inclusive by not depending crucially on the subject having proposed a formal experiment; they are somewhat more operational (possible to agree on recognising) in emphasising a process rather than a product; and the first one fits the Fundamental Paradox better by being somewhat broader than the set of carefully designed scientific Gedanken experiments.

Mechanisms: What Processes Do Scientists Use to Run TEs?

It is difficult to analyse the mental processes that allow a scientist to generate and run a TE during an investigation by using historical data because the original thought process can easily be buried under many changes and refinements the author carries out before publishing a thought experiment. Also, for many TEs it is hard to know whether they were originally part of a discovery process or created after the investigation to convince others. Nevertheless, working from the thought experiments themselves, a number of authors have hypothesised at least a rough description of processes that may have been involved. Debates have emerged amongst disparate theories ranging from those defending an empiricist view to those proposing a rationalist alternative.

Several intermediate positions have been postulated. Miriam Reiner and John Gilbert (2000) ask what is the source of conviction in TEs. They point out, for instance, that Poisson conducted a TE that led him to make a professionally high-risk claim – without having performed the experiment. They theorise that the intellectual power of a TE is in the integration of conceptuo-logical beliefs, mental visual imagery and bodily knowledge, and suggest that the last two bring tacit knowledge to bear on the problem. Nersessian (1992) hypothesised that TEs utilise simulative mental models and that The constructed situation inherits empirical force by being abstracted from both our experiences and activities in, and our knowledge, conceptualizations, and assumptions of, the world (p. 297). Likewise, Reiner (1998) posited that one necessary component for thought experimentation is construction of mental imagery in order to build the hypothetical world of a TE.

Clement (1994) attempted to speak to mechanism questions on the basis of real-time data by looking for imagery indicators in videotapes of experts. The bold type in the two episodes above denotes several instances of imagery indicators. In order of appearance, they are: Episode 1 – announces intent to form image, kinesthetic imagery report; Episode 2 – announces intent to form image, imagery report and depictive gestures.

Such imagery indicators accompanied many TEs in these videotapes, leading to the proposal that a process of imagistic simulation underlay those TEs. In this process, a perceptual motor schema generates dynamic imagery, complemented by nonformal, rationalistic contributions from general spatial reasoning operations and the ability to combine two such schemas in new combinations. Evidence from these studies suggests that premises can be in the form of implicit physical intuitions apprehended in imagistic simulations rather than being explicit linguistic propositions or axioms, and that reasoning with these can involve spatial reasoning or constructed compound simulations that are less formal than rule-based arguments. These mechanisms provided a way to speak to the TE paradox, showing how a TE could feel empirical but actually involve a considerable amount of reasoning inside the head (Clement 2008, 2009). Much of the prior work on this topic has involved the analysis of TE cases from the history of science; only recently has data been collected on the process of producing and running TEs.

Analytical Schemes for TEs

Several investigators have suggested analytical schemes for TEs. For instance, Reiner (1998) identified a five-part structure of TEs: hypothetical world, hypothesis, experiment, results and conclusion. She hypothesised that the conclusion of a TE is based on logical derivations, although in a later paper (Reiner and Gilbert 2000) she stressed that TEs have a nonpropositional aspect. The extent of the role of logical derivation has also been examined by Clement (2008). This analysis of spontaneous expert TEs indicates that TEs are often run in a nonformal, imagistic or intuitive manner.

How TEs Can Go Wrong

Miriam Reiner and Lior Burko (2003) analyse five TEs from history of science according to Reiner's five stages (1998) and identify stages at which errors occurred.

In the TEs studied, errors were usually made in the first two stages: constructing the hypothetical world and formulating the hypothesis. Reiner and Burko draw implications for the use of TEs in education; this will be discussed further below.

Review of Previous Studies on Roles Thought Experiments Can Play in Science Instruction

TEs Can Be Used by Students

Early work by Hugh Helm et al. (1985) describes students spontaneously generating their own TEs. Since then, a number of studies have documented the fact that TEs can be used by students in educational contexts. In most of these studies, Sorensen's definition is used or the concept of TE is left undefined.

Reiner (1998) found that episodes containing at least three parts from her five-part structure of TEs (described in the expert section above) were prevalent in the transcripts of 12 grade-eleven students working in small groups at computers with interactive schematic representations. In this study, it was assumed that interactive graphical dynamic representations generated by computer served as 'basic tools for learning processes that require(d) imagery' (p. 1046). Therefore, the imagery of the students was scaffolded by a display jointly viewed by several students. It might not seem surprising that, in Reiner's view, these students appeared to share mental animations that yielded similar results. However, Reiner also documents instances where students reasoned about variations of the system that had not yet been shown on the screen and agreed on predictions for these absent configurations. Especially in these instances, she argues, the students appeared to be relying on mental imagery. Working with older students, Reiner and Gilbert (2000) observed senior undergraduate physics majors and physics education majors as they solved problems designed to elicit TEs. They found that thought experimentation was a frequently used strategy.

In another instructional approach, Gilbert and Reiner (2004) found that 12- and 13-year-old students working in small groups constructed and ran thought experiments intertwined with the processes of conducting physical experiments. Transcripts showed students making progress towards scientific ideas by alternating between these imaginary and physical models. The students also used gestures and drawings to communicate ideas when trying to model how a physical system worked. This study suggests that the interplay between experiments, drawings and thought experiments can be very rich.

Maria Nunez-Oviedo et al. (2008) investigated the role of TEs with a similar age group. In middle school classrooms, the teacher was observed inviting students to run TEs both to support modification of ideas and to disconfirm ideas. Nunez-Oviedo et al. report that students were able to reason with the scenarios to arrive at scientifically accepted ideas. They argue that TEs can be used and are plausibly important at the middle school level.

Thought experiments – even Gedanken experiments – spontaneously generated and run by high school students need not be jointly constructed, though they may be inspired by the comments of other students. Lynn Stephens and John Clement (2006) found that students independently could generate novel scenarios, make predictions from those scenarios and evaluate those predictions on their own during class discussion. David Hammer (1995) considered thought experiments in high school physics class discussions as one of several kinds of process skills that were exhibited by students when the teacher in his case study took care to foster an open attitude towards contributing ideas.

Importance of TEs in Teaching and Learning

Gilbert and Reiner's (2004) work suggests that TEs can play an important role in physical (real) experimentation by suggesting modifications to physical experiments and alternating with them to lead to a convergence on accepted scientific concepts. (In their case, the concepts were of unusual sophistication for middle school level, as the students themselves spontaneously generated the beginnings of a concept of magnetic field.) Helm et al. (1985) speculate that TEs can play an important role in conceptual change because they have the ability to arouse dissatisfaction with existing conceptions. There are several questions they believe need to be answered, including: Is the classic structure of TEs drawn from physics the ideal structure of TEs to be used in pedagogical contexts? How far does TE overlap with analogy? What can be done to support students in their spontaneous generation of TEs?

Some recent studies have begun to address these and similar questions. For instance, what gives a model the ability to generate dynamic imagery, which then can be used to generate predictions during a TE? Clement (2008) hypothesised that some primitive physical intuitions have this kind of 'runnability' built into them in the form of perceptual motor schemas (such as a schema embodying ideas about pressure). When these are used as components in an explanatory model, the model can inherit this capability for generating dynamic imagery. This transfer of runnability is used to explain the ability of some analogies to serve as seed material for developing an explanatory model. So, for example, a student can develop a model of electric circuits based on a metaphor of electric pressure, with pressure spreading equally throughout equipotential (connected) areas of a circuit and pressure differences driving flow through resistors. When such a model is used to make a prediction for the first time, or used flexibly on a transfer problem involving a circuit with a type of geometry the student has never seen before, this is an instance of a thought experiment in the broad sense of the term used here; they are making an as yet untested prediction. In this case, it is being run via an imagistic simulation.

This hypothesis of transfer of runnability was supported by case study evidence (Clement and Steinberg 2002). A subject's spontaneous use of depictive gestures over drawings whilst she processed an air pressure analog case, and her use of similar gestures during later instructional circuit episodes, indicated that she was using a similar type of imagistic simulation in the two cases. Furthermore, the subject's spontaneous use of similar depictive gestures during a later posttest provided evidence that the instruction fostered development of a dynamic mental model of fluid-like flows of current caused by differences in electric pressure, a model that could generate new imagistic simulations for understanding relatively difficult transfer problems.

Thus, in addition to the use of Gedanken experiments, students making a prediction for an unfamiliar analogy or running a new model for the first time, or applying a model to an unfamiliar transfer problem, are doing an untested thought experiment. There is case study evidence from both experts and students that all of these operations can involve imagistic simulation (Clement 2008). This suggests that this kind of rationalistic, hypothetical, imagistic thinking via TEs can be important in many more learning situations than we might initially imagine, and that it is an extremely important complement to empirical and algorithmic work. A related theme was developed by Hammer (1995), who identified a number of rationalistic process goals being fulfilled in whole class discussion that are quite different from the classic, more empirically oriented process goals in science originally identified by Michael Padilla (1991). This points to the importance of understanding student use of TE processes in both the broad and narrow senses.

A Case Study

In the interest of aiding further research on TEs in instruction, we will illustrate a method using the two-tiered definition of *thought experiment* from Clement (2002) to identify transcript evidence that students can generate TEs at both tiers. We will also illustrate how a set of imagery indicators from Clement (2008) can be used to show that there is evidence for the involvement of mental imagery as students ran the TEs.

These recent analytical methods (Stephens and Clement 2010) are aimed at questions such as the following:

- Can we identify evidence that students use TEs?
- Can we identify evidence that students can generate and run their own TEs?
- Are the appearances of TEs isolated or do they have impact on classroom discussion?
- Can students evaluate TEs? Can they modify or improve them?
- Can we associate student use of imagery with the running of TEs?
- If so, can we identify evidence for particular kinds of imagery; i.e., visual or kinesthetic?

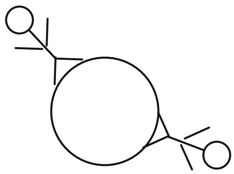


Fig. 13.2 US/Australia case

The Two-Tiered Definition Applied to Transcript Analysis

We have examined a number of transcripts of classroom activity to see whether evidence for student-generated TEs could be identified (Stephens and Clement 2006). In most of this classroom activity, guided inquiry methods of teaching and learning were being employed. We developed coding criteria based on the two-tiered definition for TEs, and we selected, for more detailed analysis, portions of transcripts where creative student reasoning appeared to be occurring. We were able to identify what seemed to us a surprising number of instances that met our criteria for student-generated thought experiments including several evaluative Gedanken experiments.

For coding purposes, the definition for the broad category of untested TEs (above) was broken into two requirements, which were coded for separately:

1. Subject attempts to predict behaviour of concrete system.
2. Subject has neither observed the experiment before nor been informed about its behaviour.

Example. A physics class is discussing possible causes for gravity including the rotation of the Earth (a common misconception). A student refers to a chalkboard drawing of the Earth with a stick figure of a man standing on it (Fig. 13.2).

> Line 40, S5: Well, I just think that gravity has nothing to do with rotation, but maybe with rotation, like, that guy is trying to get thrown off the Earth. So he's getting pulled at the same rate but he's also getting pushed away.

S5 attempts to predict the behaviour of a concrete system, a rotating Earth with a man standing on it. He has never observed the Earth from this vantage point and certainly has not experienced it spinning rapidly enough to feel the effects of being thrown off. Although his statement includes another misconception, this meets our criteria for a TE in the broad sense.

For all episodes that had been coded as having evidence for TEs in the broad sense, we applied more restrictive coding criteria to establish whether each episode also met our definition for TEs in the narrow sense, evaluative Gedanken experiments. In addition to 1 and 2 above, we required that:

3. The case appears to have been designed or selected by the subject in order to help evaluate a scientific concept, model or theory.

The TE of Line 40 above appeared to have been selected by the subject in order to help evaluate the theory that rotation is a cause of gravity and so met the additional criterion of a Gedanken experiment.

All cases that met criteria for TEs in either the broad or narrow senses were also analysed for the following factors:

- Whether the TE was generated by the teacher or the student
- Whether the TE was run by the teacher or the student

The distinction between generating a TE and running it is an interesting one. A pedagogical TE[1] can be generated in order to ask an audience to make a prediction about a system where the results are unknown to the audience but known to the generator. Often, the pedagogical TEs in the transcripts we analysed were generated by the teacher and run by the students; however, there are several incidences where we believe a student generated a TE, the outcome of which he or she was already certain, in order to convince fellow students of a point. At other times, a student generated and ran an untested TE and another student refined and reran it as a Gedanken with differing or refined results, or a student proposed a concrete case as an exemplar of some idea and another student used the case to generate an untested prediction, thus running it as an untested TE. Because of this network-like aspect of suggested test cases, untested TEs run on those cases, and Gedanken experiments (which might incorporate multiple earlier TEs from either tier), it was difficult to count the TEs in an unambiguous way until we considered the generation of TEs separately from their running.

Evidence of Spontaneous TEs from a Classroom Transcript

In Stephens and Clement (2006), the transcript under analysis was of a whole class discussion that comprised 42 min over the span of 2 days in a senior level high school physics class. The transcript began when the teacher first introduced the topic of gravity.

We organised our data by ‘case’ (denoted Case 1, Case 2 and so on), ‘variation of a case’ (denoted 1a, 3f and so on) and ‘episode’ (‘S5 reruns Case 2d as a Gedanken’). A case is a concrete example of a system, such as the case of one person standing in the United States and another standing in Australia, each person experiencing gravitational forces. A variation of a case involved the same concrete example of the system but with some variable changed in a significant way (such as being taken to extreme beyond the normal range for the system) or an additional variable highlighted. For instance, when a student introduced the rotation of the Earth into the discussion about Case 1, we counted this as Case 1a. An episode involved a single student either generating or running a case or variation.

We identified six separate cases that were topics of discussion in this transcript. These included: Case 1, a spherical mass such as a planet with one or more people

[1] This is a broader category than Gilbert and Reiner’s (2000) teaching TE in that a pedagogical TE need not be related to any existing consensus TE.

upon it experiencing gravitation; Case 2, two small objects not touching and not experiencing noticeable gravitational forces due to each other; Case 3, gravity inside a bell jar; Case 4, a spinning fair ride and the forces due to spinning felt by the riders; Case 5, a catapult and the forces experienced by a projectile and Case 6, a space ship rapidly orbiting the sun. The teacher introduced Cases 1 and 3 as part of the planned lesson; Case 1 then gave rise to numerous variations by students. The other four cases were introduced spontaneously by students.

The discussion begins with the teacher asking the students to consider a drawing on the board (Fig. 13.2). The teacher explains that the upper stick figure is standing in the United States and the lower in Australia and asks the students to vote on a ballot they have been given.

> Line I–5, T: Now. Vote Number 1 … (A)h, compared to the United States, gravity in Australia is: a little less, equal, a little bit more.

Students have differences of opinion on this, leading to a very active discussion. This is Case 1 in the chart in Fig. 13.4 below.

Soon after the teacher presents this case, S4 responds that he thinks that ‘somehow the fact that [the Earth] spins causes a lot of the main force of gravity’. This is the Spinning Earth variation, Case 1a. The student has introduced spinning as an important variable, indicating that his model of gravity includes spinning. This was not coded as a TE because the student did not make a prediction about the behaviour of the system; the outcome (that spinning causes the main force of gravity) was assumed beforehand.

Several students attempt to address this student’s misconception, including S5, who reruns the Spinning Earth case as a TE (Line 40, described above). In fact, S5’s prediction that spinning will throw ‘that guy’ off the Earth becomes a hot topic of debate in the class. Note that S5 speaks of ‘that guy’ as though it were the drawing on the board along with its stick figure that is doing the rotating. The student appears to use the case to help evaluate the effect of spinning in his mental model of gravity. Because the student did not generate the case, we have classified the episode as the running of a TE (rather than generation of a TE), and in the narrow sense (i.e., as Gedanken experimentation).

In spite of the attempts of several students to counter the idea, S4 and S6 continue to defend rotation as a cause of gravity. This leads to an incident where a student appears to adopt the case another student invented, convert it into an extreme case, and then run it as an evaluative Gedanken experiment. In Line 49, S7, who had been quiet until this point, suggests the following.

> Line 49, S7: Well, in reference to rotation and gravitational force, I think of them as being two opposite forces because if you stand on – let’s just imagine a ball floating in space you tape your feet to. And you start spinning the ball around, you’re gonna feel like you’re gonna be thrown off. But if it’s a small ball, then the attraction between you and that little small mass is negligible so that you’re just gonna feel the forces being spun around in a centrifugal force.

The massive earth has shrunk to a small ball and the spinning has increased from one revolution a day to many times a minute judging from his gestures on the videotape.

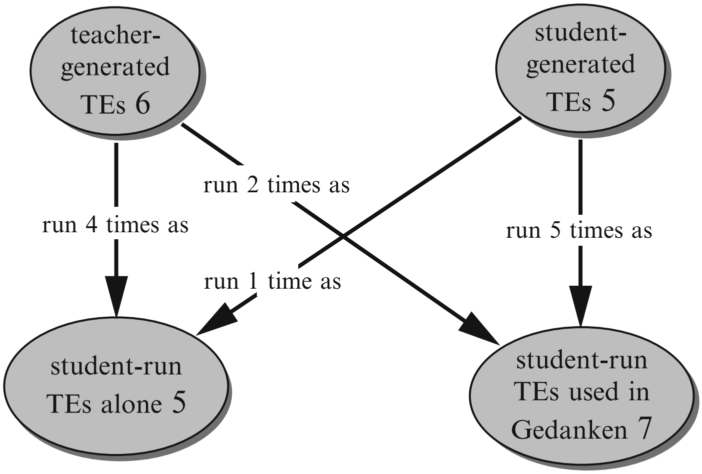


Fig. 13.3 Breakdown of TEs: TEs were run multiple times and in various combinations, so the number of TEs generated (*top row*) does not match the number of times TEs were run (*bottom row*). If the same TE was run twice by the same student, it was not double-counted

The transcript of the first day provides sufficient evidence to code five episodes of generation of untested TEs, two of them by students. Both of the latter were also coded as Gedankens. In addition, there is evidence that two students ran TEs generated by the teacher. At other points, students appear to be generating predictions but in each of those instances there is not enough information to determine whether the system in question was untested for those students (Lines 88 and 89). Coding in this conservative manner yielded four episodes in less than 20 min of tape where there was evidence for students generating and/or running TEs.

On Day 2, there was a new round of discussion in which, over 25 min, there is evidence for the generation of six new untested TEs, the first three by the teacher and the last three by students. Again, all three of the student-generated TEs were judged to be Gedankens. In addition, there were instances where students appeared to run TEs generated by other students or by the teacher.

The methodology used here resulted in the identification of evidence in 42 min of videotape for 11 episodes of TE generation, 5 of them Gedanken experiments generated by students. In addition, there was evidence for 7 episodes of students running TEs formulated by others, including 2 where they were run as Gedankens. Figure 13.3 gives a breakdown of coding results.

Evidence of Imagery Use

Whether TEs are considered in the broad or the narrower sense, there is some evidence that they can involve imagery-rich mental simulation and that this dynamic imagery can enable the user to access implicit knowledge, rendering it more explicit

(Clement 1994, 2009). Identification of imagery-use indicators (Clement 2008; Clement et al. 2005) has allowed us to address further the question of whether classroom TEs can involve dynamic imagery.

We regard depictive gestures, which appear to depict an imaginary image 'in the air' near the speaker, as providing some evidence for the involvement of mental imagery. In particular, we are interested in evidence for the use of animated or runnable mental imagery, which we obtain from gestures that appear to depict an imaginary motion or force. Identifying these types of gestures gives us a potential foothold on distinguishing between static and animated mental imagery.

For the Gedanken experiment of Line 40 discussed above, here is the same passage with gestures described.

> Line 40, S5: Well, I just think that gravity has nothing to do with rotation, but maybe with [right forefinger rotates quickly, inscribing tiny circles in the air] rotation like [points to chalkboard] that guy is trying to get [emphatic, sweeping movement with his right hand and arm, moving across the front of his body from right to left] **thrown** off the Earth. So he's getting [repeats sweeping movement] **pulled** at the same rate but he's also getting [reverses previous movement, pulling his right hand and arm back to the right] **pushed** away.

With the exception of the pointing gesture, which refers to a real object rather than an imaginary image, the rest of these gestures were coded as depictive. With video sound off, the first depictive gesture was classified as motion indicating [2] and the last three as force indicating. The written transcript was then coded for force-indicating terms. Examining the results, our classification of the last three gestures as force indicating was confirmed by the fact that force-indicating terms (in bold) co-occurred with them. In fact, the co-occurring gestures appear to depict the terms – throwing, pulling, pushing. Throughout this videotape, depictive gestures were observed in abundance.

Coding Results

After reaching agreement on the coding for the gestures, the verbal imagery indicators, TEs in the broad sense, and Gedankens, we compared the results to see how often imagery indicators coincided with evidence for TEs. Figure 13.4 is a chart of the results. The discussion is represented chronologically from left to right and top to bottom; the numbers across the top of each row are transcript line numbers. Table 13.1 shows the key to Fig. 13.4.

A sampling of features that can be seen in the kind of chart in Fig. 13.4:

- There are large blocks of transcript with no teacher-generated cases as in Lines 1–52 and Lines 199–239. Here, the students were generating the cases and maintaining the discussion.

[2] With sound off, classifying a gesture as motion indicating was considered more conservative than classifying it as force indicating. The fact that rotation implies a force to the physicist was not deemed sufficient here.

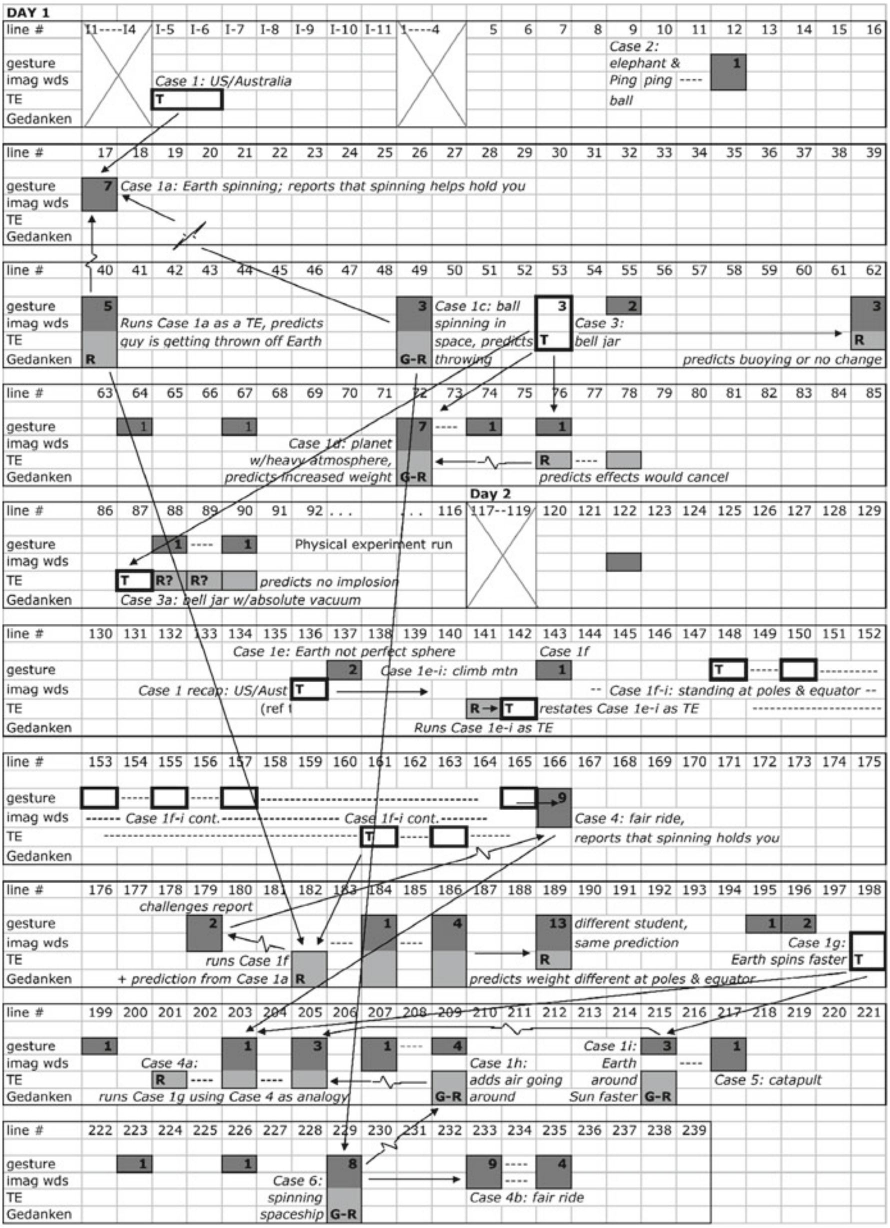
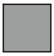
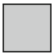
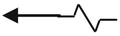
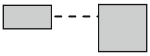


Fig. 13.4 Gravity class TEs and imagery use, Days 1 and 2

Table 13.1 Key to the chart in Fig. 13.4

Symbol	Meaning
	Imagery indicators are present.
	Both gestures and verbal imagery indicators are present.
	There is evidence for a TE in the broad sense, an untested TE.
	There is evidence for a TE in the narrow sense, a Gedanken Experiment.
T	The teacher is introducing a new case or explicitly proposing a TE.
	The later case is a variation of the earlier case or incorporates it.
	The later case appears designed to dispute the results of the earlier one.
7	7 depictive gestures (for ex.) were coded for this line of dialog.
G-R	There is evidence that a Gedanken was Generated and Run.
	An evolving case was described by a single speaker through multiple transcript lines interspersed with transcript lines spoken by others.
R?	Though a TE appears to have been run, there is not sufficient evidence to determine whether the system was untested by the student.

- We can see at a glance whether a TE was confirmatory or disconfirmatory of the idea it sought to address by whether the line connecting it to a previous case under discussion is straight or jagged.
- The individual TEs appear reactive to other TEs and to other ideas.
- We can easily see which TEs were associated with evidence for imagery by whether light grey blocks on the bottom two rows are paired with dark grey blocks directly above them.

Potential of the Methodology: Sample of Findings

This analysis, using the conceptual categories and methodology developed, demonstrates that evidence can be collected for the following (see also Stephens and Clement 2006):

1. *Thought experiments in the broad sense.* In the transcript discussed above, we found evidence for six teacher-generated and five student-generated untested TEs. There was explicit evidence from 12 transcript statements for the TEs being run by students.
2. *The involvement of imagery during the running of the TEs.* There were 14 episodes where evidence for generation or running of TEs was paired with evidence for the use of imagery. Eleven of these episodes had evidence for imagery from both gesture and verbal data.

3. *Kinesthetic imagery.* The most frequent form of evidence for imagery use in these transcripts was the use of force terms coupled with gestures that appeared to depict what the force terms were describing.
4. *Evaluative Gedanken experiments.* Students designed cases and used them to evaluate explanatory models. A few of these were discussed, but, as a look at Fig. 13.4 will reveal, there were many other instances coded.
5. Students can make sense of and discuss TEs proposed by the teacher; likewise for TEs proposed by other students.
6. TEs can spread 'contagiously' between students in a discussion, becoming modified and improved; this is an indication of the coherence of discussion.

Conclusions

Definitions

A problem in the literature is that there is no consensus on a definition of TE. In much of the literature, Sorensen's definition (Sorensen 1992) is used or the concept of TE is left undefined. An issue with Sorensen's definition is that it shifts much of the burden to the term *experiment*. TEs pose a paradox (Clement 2002, p. 32), namely, 'How can findings that carry conviction result from a new experiment conducted entirely within the head?' Motivated by the paradox, a two-tiered definition is proposed; it is more inclusive by not depending crucially on the subject having proposed a formal experiment, slightly more operational in emphasising a process rather than a product, and the broader tier fits the paradox better than the narrower set of carefully designed scientific Gedanken experiments.

Reiner (1998) has proposed a five-part structure of TEs: hypothetical world, hypothesis, experiment, results and conclusion. This provides a potentially useful fine structure; however, expert studies indicate that TEs can also be run in a nonformal or intuitive manner. A less fine-grained but perhaps more easily codable breakdown between generating and running a TE is proposed by Stephens and Clement (2010).

Existence in Classrooms

There is some initial evidence that middle and high school students can run teacher-generated TEs and Gedankens and generate and run TEs of their own. Given the broader definition for TE that has been proposed, it is possible that additional middle or elementary school student utterances will be reinterpreted as evidence for this kind of TE in the future. As for student-generated Gedankens, this may be an advanced skill. There is evidence from case studies that, on occasion, some students in physics classes have done this. An interesting question for future research is whether this skill can be taught.

Overall, this suggests that rationalistic, hypothetical thinking via TEs can be important in many more learning situations than we might initially imagine. A related theme was developed by Hammer (1995), who identified a number of rationalistic process goals being fulfilled in whole class discussion that are quite different from the classic, more empirically oriented process goals in science originally identified by Padilla (1991).

Purpose

Different kinds of TEs can be used to construct or evaluate (disconfirm or confirm) a model. Clement (2008) has identified a number of thinking processes that can incorporate and utilise TEs (defined in the broad sense), including the use of analogies, extreme cases and runnable mental models.

TE Mechanisms

There is case study evidence from gestures and other indicators from both experts and students that TEs used for all of the above purposes can involve imagistic simulation. This suggests that imagistic thinking via TEs can also be important in many more learning situations than we might initially imagine.

Ongoing work on mechanisms in expert TEs points to the involvement in many TEs of perceptual motor schemas that drive imagistic simulations with the help of spatial reasoning processes. This is providing some initial explanations for the thought experiment paradox concerning the origins of conviction in TEs.

Instructional Implications Effectiveness

In the gravity transcripts described earlier, we saw examples of creative co-construction of explanatory models for phenomena and argumentation about their validity (see also Clement and Rea-Ramirez 2008). These are valuable higher order process goals for science instruction. The generation of TEs in favour of the scientific model indicates the potential of student TEs to contribute also to content goals.

Gilbert and Reiner (2004) found that the process of alternating between experimenting empirically and experimenting in thought can lead towards a convergence on scientifically acceptable concepts. However, to date, findings on effectiveness come exclusively from case studies (e.g., Reiner and Gilbert 2000; Stephens and Clement 2006).

We end by hypothesising a possible general framework for viewing the role of imagery and TEs in instruction. First, TEs require somewhat risky, hypothetical reasoning that is different from the security of deduction or induction by enumeration. But because they usually involve stretching a concept or schema to use it in a new domain, they may be a very important learning tool. The idea of extending a schema to be used for a problem outside of its normal domain of application is one way to promote sense making by building on what is known and extending or modifying it.

Second, imagistic simulation may be a very important sense making process. If imagistic simulation is a major mechanism for sense making, then we need to find ways to foster it, as it is a very different mode of thinking from recalling memorised facts or executing algorithms. TEs in the broad sense could provide a way of promoting imagistic simulation as a key element of sense making.

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Chapter 14
Vygotsky and Primary Science

Colette Murphy

This chapter examines some of Vygotsky's ideas in relation to children's development and early learning in science. The literature concerning children's learning in science at primary (elementary) school is surprisingly neglectful of the work of Vygotsky, with most emphasis still being placed on Piagetian ideas (Anne Howe 1996). Three main Vygotskian ideas are explored in this chapter in relation to young children's learning of science: the zone of proximal development, cultural mediation and the importance of play for the development of abstract thought. The chapter contextualises Vygotsky's ideas specifically in relation to improving both children's experience of primary science and their development of scientific concepts.

Science education has historically moved between three broad theoretical frameworks that have governed policy and practice in school science: behaviourism, cognitive constructivism and sociocultural theory. Behaviourism is based on the principle that scientific learning is a behavioural change that can be induced via appropriate stimuli; it follows the work of Ivan Pavlov (1849–1936), Edward Lee Thorndike (1874–1949) and Burrhus Skinner (1904–1990). In cognitive constructivism, it is supposed that children discover scientific concepts as a consequence of applying logical thought to results of interaction with objects and phenomena; it is based mostly on the work of Jean Piaget (1896–1980). Sociocultural theory applied to science learning would suggest that learning science is bound by the specific social and cultural context available to the learner. It presupposes that learning occurs first between people and then in the individual. It argues that scientific concepts are *not* formed by repeated experiences, but by combining experiences with intellectual operations guided by language; much of this work is based on the writing of Lev Semenovich Vygotsky (1896–1934).

Both Vygotsky and Piaget maintained that children are not just small adults and that children's minds work in a different way from those of adults, using different

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means. However, whilst Piaget argued that children need to reach a certain stage of development before they can learn more complex abstractions, Vygotsky contended that learning actually leads development and that the teacher should always be challenging the children. Piaget maintained that we need to discover innate, internal laws that govern the child's mind, whereas Vygotsky highlighted the importance that culture plays in determining a child's development. Essentially, Piaget was more interested in the 'average' child, whereas Vygotsky focused on the importance of the unique social and cultural conditions that govern the learning environment of each child. Vygotsky made the case that each child is born into a particular cultural society and that his or her development is mainly directed by the internalisation of cultural signs and symbols which he or she later uses as psychological tools (e.g. memory, thinking, speech, etc.) to mediate learning (Elena Yudina 2007). Yudina gives the example of a child learning to eat with a spoon, which is mediated by an adult (usually the mother). The way in which the child uses the spoon depends on those cultural norms expressed by the mother. The spoon could be considered as an external tool to aid eating; language and gestures become internal tools to aid learning.

In terms of primary school science, Piaget's work led to the idea that children cannot be taught certain concepts until they have reached a certain developmental level and also that skills-based science learning and 'hands-on' approaches provide the most effective learning environments for classroom science. Vygotsky, on the other hand, maintained that child development is *not* a linear process and that there are different levels of development for different functions: at the one time, some cognitive functions can have 'matured', whilst others are in the process of maturing. So, children will *not* develop concepts using skills-based and hands-on approaches unless these are contextualised within an appropriate conceptual framework. Only then can the child abstract meaning from the experience. New, similar experiences can then be integrated into the conceptual framework, which becomes more familiar and concrete with each subsequent related experience.

Zone of Proximal Development

There is currently much discussion and debate about what Vygotsky actually meant by the 'zone of proximal development' (ZPD). My experience of the term was that it was the only reference to the work of Vygotsky in many education textbooks, and was never adequately explained. The simplistic definition of the ZPD found in many textbooks and other publications involves the 'gap' between what a child can achieve unaided and with help; for example, Louis Cohen et al.'s (2004) in *Guide to Teaching Practice*. This definition could be said to imply little more than that teachers need to help children! Anton Yasnitsky (2008) cites Annemarie Palincsar (1998), who argues that the ZPD is probably one of the most used and least understood educational concepts, and Mercer and Fisher (1992), who point out the danger in the term ZPD being used as a fashionable alternative to Piagetian terminology. Yasnitsky (2008) also cites Jonathan Tudge's (1999) observation that, in the six volumes of

Vygotsky's collected works, the ZPD only appears on a few pages in the thousands that he wrote. Bert van Oers (2007), however, discusses the complexity of the ZPD and shows how the concept was an evolving notion even during the short research life of Vygotsky; he used it initially as an index for intellectual potential and later as an educational concept focusing on the conditions needed to establish a ZPD.

Margaret Gredler and Carolyn Claytor Sheilds (2008) describe Vygotsky's argument that two children of the same age and the same 'actual' level of cognitive development not being able to solve a new problem with the same amount of help. Despite being measured at the same level, one child might solve the task with very little help, whilst the other might not solve it even after several different interventions designed to support the learning. Such interventions could involve: demonstrating the problem solution and seeing if the child can begin to solve it; beginning to solve it and asking the child to complete it; asking the child to solve the problem with the help of another child who is considered to be more able; and explaining the principle of the needed solution, asking leading questions, analysing the problem with the child, etc. Vygotsky considered performance on summative tests as an indication of the child's past knowledge and argued that 'instruction must be orientated towards the future, not the past' (Vygotsky 1962, p. 104). He defined the ZPD as: 'those functions which have not yet matured but are in the process of maturing… "buds" or "flowers" of development rather than "fruits" of development. The actual development level characterises the cognitive development retrospectively while the ZPD characterises it prospectively' (Vygotsky 1978, p. 86). He suggested that teaching/learning in the ZPD creates new levels of cognitive development that would not have been reached otherwise and that formal instruction is necessary to lift the child to the level of systematic scientific thinking. Useful instruction 'impels or awakens a whole series of functions that are in a stage of maturation lying in the zone of proximal development' (Vygotsky 1987, p. 212).

Bert van Oers (2007, p. 15) points out that the ZPD 'is *not* (emphasis added) a specific quality of the child, nor is it a specific quality of the educational setting or educators… it is… collaboratively produced in the interaction between the child and more knowledgeable others'. Gordon Wells (1999) and Tudge and Scrimsher (2003), together with many other researchers, also discuss the ZPD as an interaction between the students and co-participants. The interaction definition, whilst popular, is contested. Seth Chaiklin (2003) argues that the maturing functions described above by Vygotsky (1978) are not created in an interaction, but that interaction helps in identifying the existence of such functions and the extent to which they have developed.

Vygotsky contended that a full understanding of the ZPD should result in a re-evaluation of the role of 'imitation' in learning. His notion of 'imitation' is not meant as copying – more as emulation of an activity as part of the learning process. For example, a child learning to add, knit or dance emulates the teacher before doing the task by himself or herself. This type of activity coincides with the ZPD in the sense that it bridges what the child can do with help and then alone.

Vygotsky's description of the ZPD was that of maturing psychological functions that are required for the understanding of more abstract, scientific concepts. The conditions required to 'create' a ZPD to promote maturation of these functions is

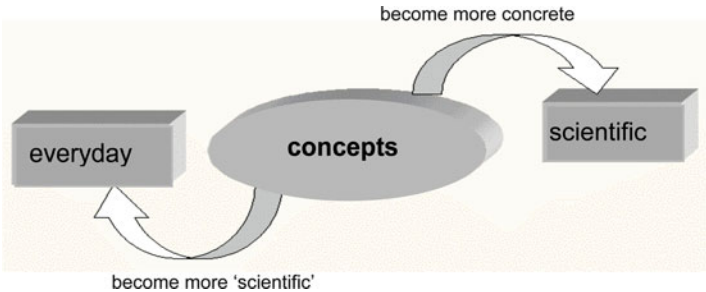

Fig. 14.1 Science concept formation as a dialectical process

of prime importance to children's early development of scientific concepts. Vygotsky maintained that scientific concept development is dialectical, as opposed to a linear process, in which spontaneous, or everyday, concepts become more abstract or scientific as a child learns. The scientific concepts, in becoming more familiar, become more concrete (see Fig. 14.1).

A zone of proximal development (ZPD), which can aid in the formation of scientific concepts, can be set up by involving children in shared activities in which they are afforded *meaningful* participation. Vytaly Rubtsov (2007) describes such a setting involving 7- to 9-year-old children:

> Two children must work together to balance a set of weights on a calibrated arm by moving, adding or removing weights. To solve this problem, they must take into account the relationship between each weight and its distance from the arm's centre of gravity. One participant is allowed to move the weights along the arm but not to add or remove weights; the other may increase or reduce the number of weights, but not move them. This division of activities, therefore, requires the two participants to work together, coordinating their activities in order to solve the task successfully. As the children move to the next problem, they switch roles. (p. 12).

Rubtsov (2007) cautions that such activities, whilst promoting reflective thinking, do *not* guarantee that each child will be able to identify the essential elements of the task. He suggests that, to increase the effectiveness of the activity, children should also use *pictorial and symbolic models* to represent the problems that they are solving and the steps that they use to solve them. Hence, they will be applying a conceptual framework into which their activity can be contextualised and made scientifically meaningful. This, I believe, is the crux of improving primary science by using a Vygotskian perspective. The pictorial and symbolic models, together with the discussion, become more meaningful to the children (and more so again with continued use with new, similar activities). Such work promotes thinking and stimulates pupils to reflect and explain in order to understand how their experiences and context-bound knowledge fit into a larger system (Howe 1996). The teacher is essential here to guide the work and provide the conceptual framework. Howe (1996) argues that, in contrast, a Piagetian approach involves children working on their activity without teacher intervention. She maintains that 'decontextualized tasks, chosen to represent a process but unrelated to children's everyday knowledge or interests, would not have a place in a science curriculum informed by a Vygotskian perspective' (p. 46).

Most science educators contrast this approach with the conceptual change model, popularised by George Posner et al. (1982) and Roger Osborne and Peter Freyberg (1985). This assumes that children come to school with misconceptions, or alternative frameworks, about natural phenomena that need to be elicited and then challenged (typically via demonstration or experimentation) to induce cognitive conflict and eventual reconciliation and acceptance of the logical, scientific concept. The conceptual change approach has been found wanting in several respects, including the observation that many 'misconceptions' persist, even after teaching involving cognitive conflict and initial acceptance of the scientific explanation has taken place (e.g. Shulman 1986). Perhaps a reason for such persistence of 'misconceptions' is the lack of relevant context for the pupils when the learning takes place. Howe (1996) argues that, using a Vygotskian perspective, children's ideas would be elicited, *not* to be challenged, and used to 'establish a foundation on which to build new knowledge or as a point of entry into the system of relationships that are eventually to be understood' (p. 48). Such understanding requires *time* so that children can move back and forth between everyday and scientific concepts, making sense of and discussing experiences in relation to the conceptual framework. The emphasis here is *not* on the solitary learner, but on interacting, negotiating and sharing to help integrate everyday concepts into the system of relational concepts. Howe (1996) raises some very important research questions based on a Vygotskian approach to science learning: 'What problem solving strategies do children use in everyday life that have been ignored in school and can be used as a basis for science teaching? What are the differences between the everyday science concepts of children from different socioeconomic, ethnic and regional backgrounds and how does this affect what is learned?' (p. 48).

Play

There is a vast amount of literature about play in primary science, with much of it debating whether the focus should be on teaching academic skills or engaging young children in make-believe play as a developmental activity (Elena Bodrova and Deborah Leong 2007). Recently, much of the focus tends to be more in the direction of the former. Bodrova and Leong (2007) suggest that there is a false dichotomy between play and academic skills when considered from a Vygotskian perspective. Indeed, Vygotsky maintained that creating an imaginary situation in play is a means by which a child can develop abstract thought. He considered play as a precursor to academic learning in two ways (Fig. 14.2).

The best kind of play to develop abstract thought involves children in using unstructured and multifunctional props, as opposed to those that are realistic. The former type of props strongly promotes language development to describe their use (e.g. a cardboard box can serve first as a shop, then as a school, then as home). Vygotsky said that this repeated naming and renaming in play helps children to master the symbolic nature of words, which leads to the realisation of the relationship

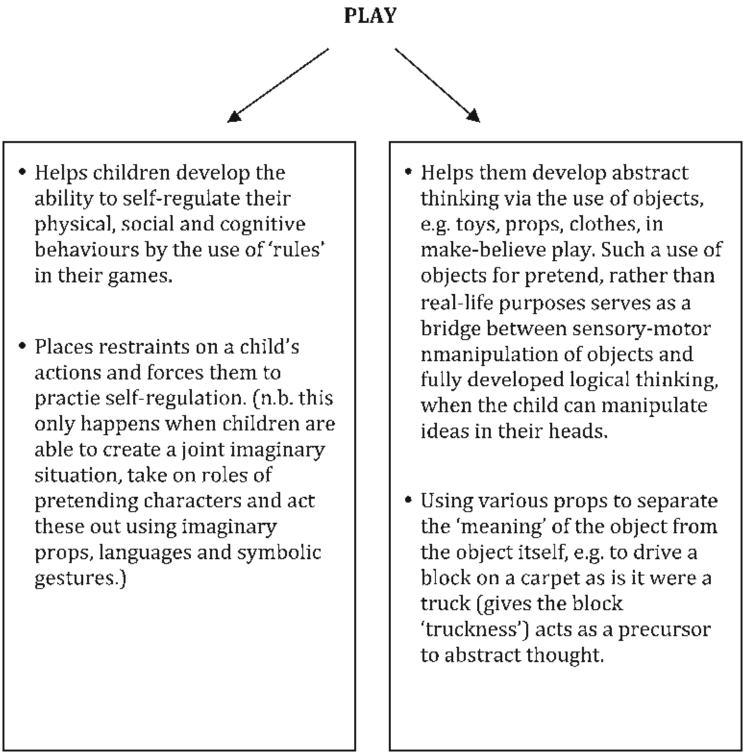

Fig. 14.2 Ways in which imaginative play is a precursor to academic learning

between words and objects and then of knowledge and the way in which knowledge operates.

This type of play is not often seen in the classroom in school – many 3- to 5-year-old children are playing like toddlers, just manipulating objects and not engaging significantly with other children.

Vygotsky's perspective on play connects it to the social context in which a child is brought up. He suggested that adults and older children should also be involved to enable younger children to model both roles and the use of props. Vygotsky promoted the notion that play, as learning, should lead development, as opposed to the more accepted one of development leading learning or play. Nikolai Veresov (2004) discusses learning that takes place in or within children's play. He uses the Vygotskian example of a child playing with a stick by using it as a horse. The child learns about the object (stick) and its objective physical properties, but also decides whether such properties allow or prevent the stick from becoming a horse. If the object does not suit the play task, the child stops playing with it. Veresov, in the same article, proposes that learning in play is a movement from the field of sense to the field of meaning; 'sense finds a suitable object, that is, sense objectifies itself' (p. 13). He exemplifies the sense-meaning dimension using a teacher-child two-part vignette in which the teacher first asks the child to suppose that he has two apples, and then gives one to someone and asks the child how many apples he now has. ‘Two’ replies the child and, on further questioning, he tells the teacher that he has two because he never gives his apples to anyone else. In the second part, the teacher asks the same child to suppose that someone else has two apples and gives one to him – she asks how many apples the other person now has. The child replies ‘one’ and explains that he or she would have one each. Veresov (2004) argues that the task is the same (a calculation of 2–1=1), but that the sense of the task must be in the child’s zone of proximal development.

Vygotsky theorists point towards empowering children through play. For example when modelling a situation in play involving, say, an imaginary parent or teacher or grocer or doctor, the child becomes, in Vygotsky’s terms, ‘a head taller’. Vygotsky (1978, p. 102) himself suggested that play creates a ZPD of the child:

> This strict subordination to rules [during play] is quite impossible in life, but in play it becomes possible: thus, play creates a zone of proximal development… In play a child always behaves beyond his average age, above his daily behavior; in play it is as though he were a head taller than himself.

In primary science, a Vygotskian perspective would presuppose that teachers promote role-plays and imaginary play in science learning for children throughout the primary school in order to further the development of abstract, conceptual thought. There would be a lot less focus on individual play with objects and more on collective play, preferably involving older children who can model both roles and the use of props for the younger ones.

Cultural Mediation

Whilst it is a common observation that children learn from adults and other children, it is less obvious how this happens. Vygotsky suggested that the child appropriates cultural tools and ways to use them; the child interacts with the environment via the mediation of cultural agents. The child is the subject, not the object of learning (Yudina 2007). Piaget, on the other hand, argued that the child’s learning represented biological adaptation to the environment, a far more passive role.

The main cultural tool, according to Vygotsky, is language, which can be thought of as a sign system. For learning to take place, language first needs to be internalised by the child (see Fig. 14.3). Vygotsky noted the importance of cultural mediation of these sign systems in humans, which does not occur in animals. For instance, in the everyday activity of eating, animals of a particular species all eat in the same way whereas, in humans, the way in which a person eats strongly reflects the culture in which they were raised and there are many, many different ways in which humans consume their food. Vygotsky argues that cultural mediation is just as important in the consideration of how, and indeed what, children learn.

In terms of learning, it must be remembered that the ‘mediator’, such as language, carries *meaning and sense*, as well as functioning as a tool, and therefore must be *interpreted* by the child (Vladimir Zinchenko 2007). Therefore, the child contributes

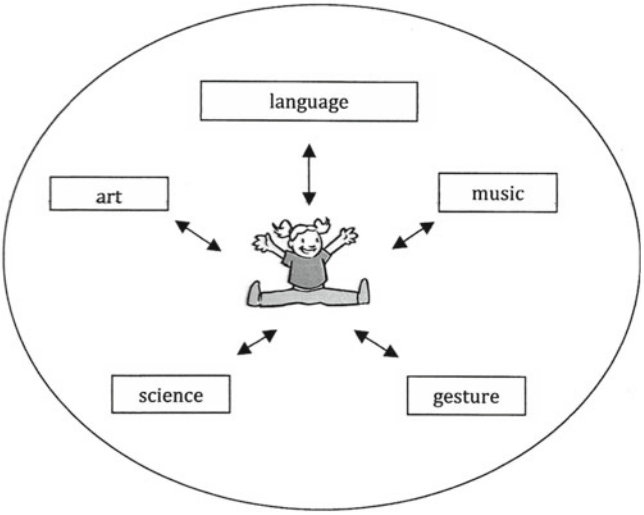

Fig. 14.3 Examples of sign systems used by a child to interact with the external world

to the culture, and continues this contribution in many ways throughout his or her life. Children's learning by way of cultural mediation can be summed up as follows:

$$\text{child} \xrightarrow[\text{mediated by cultural agent}]{\text{interacts with environment}} \text{higher psychological functions}$$

Yuriy Karpov and Carl Haywood (1998) argued that Vygotsky maintained that education entails two fundamental forms of mediation: mediation via cultural concepts and mediation via social interaction, which can be considered separately, but are in reality inseparable. It is through such mediation, according to Vygotsky, that 'we can take stock not only of today's completed processes of development, not only of cycles that are already concluded and done, not only of processes of maturation that are completed; we can also take stock of processes that are now in the state of coming into being, that are ripening, or only developing' (Wertsch (1985), pp. 447–448; cited in Wertsch 1985, p. 68). In order to aim the mediation at those abilities that are in the process of ripening, teachers must be assessing the children's learning before and during, as well as after, each learning sequence. The current emphasis on different modes of formative assessment, or assessment for learning (AfL) (see Black and Wiliams 1998), provides a basis upon which this can be achieved.

The role of the children in learning and development is much more active and agentic in a Vygotskian interpretation of how learning occurs through interaction with their environment, than if we use the Piagetian model based on their adaptation to the environment. Piaget's model leaves little room for the child to alter the environment as a consequence of his or her learning. In primary science learning, the Vygotskian interpretation allows for the sharing of ideas about phenomena between children and their peers and teachers, which is essential for the exposure of different levels of understanding to be addressed. Vygotsky contended that higher cognitive functions originate from the interaction between people, but we need to *teach* decontextualised contexts to enable the facilitation of cognitive growth. Teaching decontextualised concepts with the experience enables the students to create and enliven a cognitive framework in which they can contextualise and abstract their experiences! The fact that a person boils water in a kettle and observes steam coming out for years, does not necessarily (and only very rarely) lead to them discovering the concept of evaporation. Only when they are taught about evaporation and encouraged to link this learning with the kettle experience can most people make sense of the decontextualised concept of evaporation, and to situate other experiences, such as the drying up of puddles, within the initial framework of evaporation and then in the broader conceptual framework of the water cycle.

Conclusion

According to Vygotsky, learning *leads* development; so do not wait until children are 'old' enough to learn! Leif Strandberg (2007) contends that, as teachers, we need to promote activities that: develop interactions between children and between adults and children; give children access to tools and words; change around the learning environment to suit different activities and involve children as creative coworkers (see Fig. 14.4).

Such methods liberate adults and children from a retrospective, diagnostic and resigned pedagogy and enable a more forward-looking perspective on learning comprising performing as opposed to explaining. They also provide, according to Strandberg (2007), a sense of hopefulness for what comes next.

In primary science activities, teachers might consider expanding their use of curricular activities that include:

- Think, pair share
- Peer learning
- Mediational artefacts
- Science term of the day (or week)
- Adaptation of the learning environment
- Use of role-play and stories to promote Vygotsky-type imaginary play
- Extending 'play' activities to older children to aid abstract concept formation.

In summary, a Vygotskian approach to primary science highlights the importance of ensuring that practical activities are contextualised within a conceptual framework, children are encouraged to discuss their developing understanding with peers and teachers, and time is allowed for contextualised experiences that foster the development of such concepts. Role-play and collaborative, imaginative play with children of different age groups would be encouraged throughout the primary school to facilitate the development of abstract thought. Teachers mediate pupils' learning by addressing social and cultural influences in their provision of appropriate educational tools and

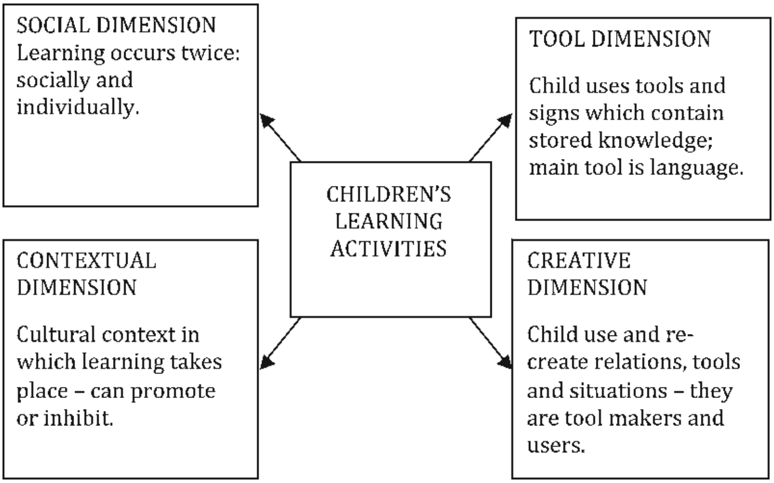

Fig. 14.4 Strandberg's four dimensions to children's activities

they monitor children's progress as they attempt to identify and teach within their zones of proximal development. Teachers use formal instruction alongside hands-on practical activities that are relevant to their experience and interests to enable children constantly to switch between everyday and scientific concepts until they have been adjudged to have achieved an appropriate understanding. It could be argued that such a change in teaching/learning approach requires a level of theoretical synthesis between some of Piaget's ideas, which dominate much of the current enactment of science teaching, with the more operational aspects of Vygotskian theory. In this regard, we can learn a lot from the literature on incorporating Vygotskian approaches to teaching in early years and in second language learning.

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Chapter 15
Learning In and From Science Laboratories

Avi Hofstein and Per M. Kind

Introduction: The Science Laboratory in School Settings

Since the nineteenth century when schools began to teach science systematically, the laboratory became a distinctive feature of science education (Edgeworth and Edgeworth 1811 cited by Rosen 1954). After the First World War, with the rapid increase of science knowledge, the laboratory was used mainly as a means for confirmation and illustration of information learnt previously in a lecture or from a textbook. With the reform in science education in the 1960s, both in the USA and the UK, the ideal became to engage students with investigations, discoveries, inquiry and problem-solving activities. In other words, based on Lee Shulman and Pinchas Tamir's (1973) review, the laboratory became the core of the science learning process and science instruction. Over the years, the science laboratory was extensively and comprehensively researched and hundreds of research papers and doctoral dissertations were published all over the world (Hofstein and Lunetta 1982, 2004; Lazarowitz and Tamir 1994; Lunetta et al. 2007). This embrace of practical work, however, has been contrasted with challenges and serious questions about its efficiency and benefits (Hofstein and Lunetta 2004; Hodson 1993; Millar 1989). For many teachers (and often curriculum developers), practical work means simple recipe-type activities that students follow without the necessary mental engagement. The aimed-for ideal of open-ended inquiry, in which students have opportunities to plan an experiment, to ask questions, to hypothesise and to plan an experiment again to verify or reject their hypothesis, happens more rarely – and when it does, the learning outcome is much discussed.

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This chapter reviews research on practical work in order to demonstrate not only its potential but also its challenges and problems. A main point to be made is that practical work is not a static issue but something that has evolved gradually over the years, and which is still developing. The development relates to changing aims for science education, to developments in understanding about science learning, to changing views and understanding of science inquiry and to more recent developments in educational technologies. To demonstrate this, we start with a review along historical lines, looking back at practical work research over the last 50 years during three periods: (1) 1960s to mid-1980s, (2) mid-1980s to mid-1990s and (3) the last 15 years. Following from this review, the second part of the chapter elaborates four different themes that summarise the state of affairs of practical work at the beginning of the twenty-first century and points towards new possibilities: how is practical work used by teachers, the influence of new technologies, 'metacognition' as a factor in laboratory learning and the issue of 'scientific argumentation' as a replacement for 'scientific method'.

Throughout the chapter, we use interchangeably the terms *practical work*, which is common in the UK context, and *laboratory work*, which is common in USA. A precise definition is difficult because these terms embrace an array of activities in schools, but generally they refer to experiences in school settings in which students interact with equipment and materials or secondary sources of data to observe and understand the natural world (Hegarty-Hazel 1990).

Fifty Years of Laboratory Work Research and Practice

1960s to Mid-1980s: Unfulfilled Ideals

This period is associated with the many curriculum projects that were developed to renew and improve science education. The projects started in the late 1950s with focus on updating and re-organising content knowledge in the science curricula, but soon reformists turned their attention towards *science process* as a main aim and organising principle for science education, as expressed by Sunee Klainin (1988) in Thailand:

> Many science educators and philosophers of science education (e.g. in the USA: Schwab, 1962; Rutherford and Gardner, 1970) regarded science education as a process of thought and action, as a means of acquiring new knowledge, and a means of understanding the natural world. (p. 171)

The emphasis on the processes rather than the products of science was fuelled by many initiatives and satisfied different interests. Some educators wanted a return to a more student-oriented pedagogy after the early reform projects which they thought paid too much attention to subject knowledge. Others regarded science process as the solution to the rapid development of knowledge in science and technology: mastering science processes was seen as more sustainable and therefore a way of making students prepared for the unknown challenges of the future. Most importantly, developments in cognitive psychology drew attention towards reasoning processes and scientific thinking. Psychologists such as Bruner, Piaget and Gagne helped to explain the thinking involved in the science process and inspired the idea that science teaching could help to develop this type of thinking in young people.

Although this development was found in its explicit form in the US, it was soon echoed in many other nations (Bates 1978; Hofstein and Lunetta 1982). Everywhere, the laboratory and practical work were put into focus. John Kerr (1963) in the UK suggested that practical work should be integrated with theoretical work in the sciences and should be used for its contribution to provide facts through investigations and, consequently, to arrive at principles that are related to these facts. This became a guiding principle in many of the Nuffield curriculum projects that were developed in the late 1960s and early 1970s.

The interest for practical work in science education research in this period is clearly demonstrated by Reuven Lazarowitz and Pinchas Tamir (1994) in their review on laboratory work. They identified 37 reviews on issues of the laboratory in the context of science education (Bryce and Robertson 1985; Hofstein and Lunetta 1982; Shulman and Tamir 1973). These reviews expressed a similarly strong belief regarding the potential of practical work in the curriculum, but also recognised important difficulties in obtaining convincing data on the educational effectiveness of such teaching. Not surprisingly, the only area in which laboratory work showed a real advantage (when compared to the nonpractical learning modes) was the development of laboratory manipulative skills. For conceptual understanding, critical thinking and understanding of the nature of science, there were little or no differences.

Lazarowitz and Tamir suggested that one reason for this relates to the use of inadequate assessment and research procedures. Quantitative research methods were not adequate for the research purpose but, at the time, qualitative research methods generally were disregarded in the science education community. Avi Hofstein and Vincent Lunetta (1982) identified several methodological shortcomings in research designs: insufficient control over laboratory procedures (including laboratory manuals, teacher behaviour and assessment of students' achievement and progress in the (laboratory); inappropriate samples and the use of measures that were not sensitive or relevant to laboratory processes and procedures.

Another issue was that teaching practice in the laboratory did not change as easily towards an open-ended style of teaching as the curriculum projects suggested. Teachers rather preferred a safer 'cookbook' approach (Tamir and Lunetta 1981). Alex Johnstone and Alasdair Wham (1982) claimed that educators underestimated the high cognitive demand of practical work on the learner. During practical work, the student has to handle a vast amount of information regarding the names of equipment and materials, instructions regarding the process, data and observations, thus causing overload on the student's working memory. This makes laboratory learning complicated rather than a simple and safe way towards learning.

Adding to this rather ominous picture, however, are some research studies and findings during this period that came to influence later developments more positively.

One area that was researched quite extensively concerns *intellectual development*. Jack Renner and Anthony Lawson (1973) and Robert Karplus (1977) (based on Jean Piaget 1970) developed the *learning cycle* that consisted of the following stages: *exploration*, in which the student manipulates concrete materials; *concept introduction*, in which the teacher introduces scientific concepts and, finally, *concept application*, in which the student investigates further questions and applies the new concept to novel situations. Many interpreters of Piaget's work (e.g. Robert Karplus 1977) inferred that work with concrete objects (provided in practical experiences) is an essential part of the development of logical thinking, particularly at the stage prior to the development of formal operations.

Another important contribution was made in the UK by Richard Kempa and John Ward (1975), who suggested a four-phase taxonomy to describe the overall process of practical work: (1) planning an investigation (experiment), (2) carrying out the experiment, (3) observations and (4) analysis, application and explanation. Tamir (1974) in Israel designed an inquiry-oriented laboratory examination in which the student was assessed on the bases of manipulation, self-reliance, observation, experimental design, communication and reasoning. These could serve as an organiser of laboratory objectives that could help in the design of meaningful instruments to assess outcomes of laboratory work. In addition, these had the potential to serve as a basis for continuous assessment of students' achievements and progress and also for the implementation of practical examinations (Ben-Zvi et al. 1976; Hofstein 2004; Tamir 1974).

Mid-1980s to Mid-1990s: The Constructivist Influence

During the period from the mid-1980s to the mid-1990s, practical work was challenged in two different ways. One was related to an increasing awareness amongst science education researchers of a failure of establishing the intended pedagogy in the reform projects from the previous period. This was expressed by Paul Hurd (1983) and Robert Yager (1984), who reported laboratory work in schools tended to focus on following instructions, getting the right answer or manipulating equipment. Students failed to achieve the conceptual and procedural understandings that were intended. Very often, students failed to understand the relationship between the purpose of the investigation and design of the experiments (Lunetta et al. 2007). In addition, there was little evidence that students were provided with opportunities and time to wrestle with the nature of science and its alignment with laboratory work. Students seldom noted the discrepancies between their own concepts, their peers' concepts and the concepts of the science community (Eylon and Linn 1988; Tobin 1990). In sum, practical work meant manipulating equipment and materials, but not ideas.

The other challenge involved the theoretical underpinning of laboratory work. The process approach was challenged by a new perspective on science education known as *constructivism*. The constructivist area started in the late 1970s with increasing criticisms against the Piagetian influence on science education. New voices argued that too much attention had been paid towards general cognitive skills in science learning and that science educators had missed the importance of students' conceptual development (e.g. Driver and Easley 1978).

The effects of this criticism can be followed in the UK in the aftermath of the Nuffield curriculum reform projects, which had contributed towards a strong foothold for the science laboratory. John Beatty and Brian Woolnough (1982) reported that 11–13-year olds typically spent over half of their science lesson time doing practical activities. This was also a period of the Assessment for Performance Unit (APU), a national assessment project within a process-led theoretical framework (Murphy and Gott 1984), which later influenced the national curriculum and its aligned assessment system.

During the 1980s, researchers started to question this practice and its theoretical underpinning in the light of philosophical and sociological accounts associated with constructivism (Millar and Driver 1987). The argument was that the entire science education community had been misled by a naïve empiricist view of science, referred to by Robin Millar (1989) as the Standard Science Education (SSE) view. The SSE view presents science as a simple application of a stepwise method, and further relates these steps to particular intellectual and practical skills. In other words, by having the right skills and by applying 'the scientific method', anyone can develop scientific knowledge. With the denial of this view of science inquiry, science educators were in need of an alternative, but finding this took some time and required a series of developments.

Two different attempts to develop alternative theoretical platforms appeared on the UK scene in the late 1980s and early 1990s. The first attempt had its inspiration from Michael Polanyi's (1958) concept of 'tacit knowledge'. This approach had similarities to the process approach, but denied the possibility of identifying individual processes (Woolnough and Allsop 1985). Rather, it was claimed that science is like a 'craftsmanship' and that investigations should be treated like a 'holistic process' based on understandings that cannot be explicitly expressed. The belief was that inquiry at school with a trained scientist (i.e. the teacher) developed this craftsmanship, and made students generally better problem solvers (Watts 1991). Retrospectively, we can see this approach as avoiding the challenge of identifying what it really means to do science by making the process hidden and mysterious.

The other theoretical approach also held on to science as a problem-solving process, but avoided the mistake in previous theories of focusing too strongly on skills. Richard Gott and Sandra Duggan (1995) claimed that the ability to do scientific inquiry was based fundamentally on procedural knowledge (i.e. understanding required in knowing how to do science). When scientists carry out their research, they have a toolkit of knowledge about community standards and what procedures to follow to satisfy these. The aim of science inquiry is not only to find new theories, but also to establish evidence that a theory is 'trustworthy'. They therefore claimed that students should be taught procedural understanding along with conceptual understanding, and then get practice in problem solving based on these two components.

At the end of the second period, constructivism was well established in science education. The teaching of skills and procedures of scientific inquiry had lost much of its status as science educators paid more interest to conceptual learning. One influential idea was the use of Predict-Observe-Explain (POE) tasks (Gunstone and Mitchell and the Children Science Group 1988). In these tasks, observations in the laboratory are used to challenge students' ideas and help to develop explanations in line with the correct scientific theories. Richard Gunstone (1991) and Richard White (1991) also made another statement about of the constructivist message for the science laboratory teaching. In particular, it was claimed that all observations are theory-laden. This means that doing practical work is no guarantee for adopting the right theoretical perspective. Students need to reflect on observations and experiences in light of their conceptual knowledge. Kenneth Tobin (1990) wrote that: 'Laboratory activities appeal as a way of allowing students to learn with understanding and, at the same time, engage in the process of constructing knowledge by doing science' (p. 405). To attain this goal, he suggested that students should be provided with opportunities in the laboratory to reflect on findings, clarify understandings and misunderstandings with peers and consult a range of resources that include teachers, books and other learning materials. His review reported that such opportunities rarely exist because teachers are so often preoccupied with technical and managerial activities in the laboratory. Richard Gunstone and John Baird (1988) pointed towards the importance of metacognition for this to happen. White (1991) also argued that the laboratory helps students in building up 'episodic' memories that can support later development of conceptual knowledge.

Period After Mid-1990s: A New Area of Change

During the last 15 years, we have seen major changes in science education. These were caused partly by globalisation and rapid technological development, which call for educational systems with high-quality science education to meet international competition and develop the knowledge and competencies needed in modern society. In the USA, we have seen developments regarding 'standards' for science education (NRC 1996, 2005) that provide clear support for inquiry learning both as content and as high-order learning skills that include, in the context of the laboratory, planning an experiment, observing, asking relevant questions, hypothesising and analysing experimental results (Rodger Bybee 2000). In addition, we observed internationally that there has been a high frequency of curriculum reforms. A central point has been to make science education better adapted to the needs of all citizens (AAAS 1991).

It is recognised that citizens' needs include more than just scientific knowledge. In everyday life, science is often involved in public debate and used as evidence to support political views. Science also frequently presents findings and information that challenge existing norms and ethical standards in society. Mostly it is cutting-edge science and not established theories that are at play. For this reason, it does not help to know textbook science, but rather it is necessary to have knowledge *about* science. Robin Millar and Jonathan Osborne (1999) suggested in this context that citizens need to understand principles of scientific inquiry and how science operates at a social level. The natural question, of course, is to what degree and in what ways the science laboratory can help to provide students with such understanding.

Another area of change in the recent period has been further development of constructivist perspectives into sociocultural views of learning and of science. The sociocultural view of science emphasises that science knowledge is socially constructed. Scientific inquiry, accordingly, is seen to include a process in which explanations are developed to make sense of data and then presented to a community of peers for critique, debate, and revision (Duschl and Osborne 2002). This re-conceptualisation of science from an individual to a social perspective has fundamentally changed the view of experiments as a way of portraying the scientific method. Rather than seeing the procedural steps of the experiment as the scientific method, practical work is now valued for the role that it plays in providing evidence for knowledge claims according to Rosalind Driver, John Leach, Robin Millar and Philip Scott (Driver et al. 2000). The term scientific method, as such, has lost much of its valour (Jenkins 2007).

The *sociocultural* view of learning is based on a Vygotskian perspective pointing towards the role of social interaction in learning and thinking processes (Vygotsky 1978). It is believed that thinking processes originate from socially mediated activities, particularly through the mediation of language. As a consequence, science learning is seen as socialisation into a scientific culture (Driver et al. 2000). Students therefore need opportunities to practise using their science ideas and thinking through talking with each other and with the science teacher (Scott 1998).

All these changes have obvious relevance for practical work. Rather than training science specialists, the laboratory should now help the average citizen to understand *about* science and to develop skills useful in evaluating scientific claims in everyday life. Rather than promoting the scientific method, the laboratory should focus on how we know what we know and why we believe certain statements rather than competing alternatives (Duschl and Grandy 2007). The socialcultural learning perspective also provides reasons to re-visit group work in the school laboratory. Most importantly, the current changes have finally produced an alternative to the science process approach and the SSE-view (Millar 1989) established 50 years ago. We now find a new rationale for understanding science inquiry and how this can link with laboratory work at school.

Emerging Themes

In the remainder of this chapter, we look into four themes that further elaborate the current situation for laboratory work in science education research and practice.

Teachers' and Students' Practice in Science Laboratories: How Are Laboratories Used?

To what degree has the use of practical work changed at schools? In this section, we look at research into how laboratories are used by teachers and students, as well as the nature of laboratory activities and facilities.

On the basis of a comprehensive study of the implementation of the laboratory in schools in British Columbia (Gardiner and Farrangher 1997), it was found that, although many biology teachers articulated philosophies that appeared to support a hands-on investigative approach with authentic learning experiences, the classroom practices of those teachers did not generally appear to be consistent with their stated philosophies. Several studies have reported that very often teachers involve students principally in relatively low-level, routine activities in laboratories and that teacher–student interactions focused principally on low-level procedural questions and answers. Ron Marx et al. (1998) reported that science teachers often have difficulty in helping students to ask thoughtful questions, design investigations and draw conclusions from data. Similar findings were reported regarding chemistry laboratory settings (De Carlo and Rubba 1994). More recently, Ian Abrahams and Robin Millar (2008) in the UK investigated the effectiveness of practical work by analysing a sample of 25 typical science lessons involving practical work in English secondary schools. They concluded that the teachers' focus in these lessons was predominantly on making students manipulate physical objects and equipment. Hardly any teacher focused on the cognitive challenge of linking observations and experiences to conceptual ideas. Neither was there any focus on developing students' understanding of scientific inquiry procedures. A comprehensive and long-term study on the use (and objectives) of laboratories in several EU countries was conducted by Marie Sere (2002). In this research, based on 23 case studies, it was found that laboratory work was perceived as an essential ingredient of the experimental sciences. However, it was also found that the objectives stated for practical work (including conceptual understanding, understanding of theories and laws and high-order learning skills) were too numerous and demanding to be implemented by the average science teacher in their respective classrooms.

These findings echo the situation at any time in the history of school science. Basic elements of teachers' implementation of practical work do not seem to have changed over the last century; students still carry out recipe-type activities that are supposed to reflect science procedures and teach science knowledge, but which in general fail on both. This is not to say everything is the same. Science education has moved forwards during the last decades with associated improvement in teachers' professional knowledge and classroom practice, but this improvement has not sufficiently caught up with the challenges of using laboratory work in an efficient and appropriate way. Teachers still do not perceive what is required to make laboratory activities serve as a principal means of enabling students to construct meaningful understanding of science, and they do not engage students in laboratory activities in ways that are likely to promote the development of science concepts. In addition, many teachers do not perceive that helping students to understand how scientific knowledge is developed and used in a scientific community is an especially important goal of laboratory activities for their students.

Today's conclusion has therefore not changed substantially from what Brian Woolnough and Terry Allsop (1985) claimed:

> Teachers at present are ill prepared to teach effectively in the laboratory. A major reason is that most science teachers have themselves brought-up on a diet of content dominated cookery book-type practical work and many have got in their habit of propagating it themselves. (p. 80)

Aligned with this situation for teachers, we find a matching picture in students' experiences and laboratory teaching materials. Attempts have been made to develop protocols for analysing laboratory activities (Lunetta and Tamir 1979; Millar et al. 1999). Darrell Fisher et al. (1999) used Lunetta and Tamir's protocol to analyse laboratory guides in Australia. The analyses suggest that, to date, many students engage in laboratory activities in which they follow recipes and gather and record data without a clear sense of the purposes and procedures of their investigation and their interconnections. Daniel Domin (1998) in the USA found that students are seldom given opportunities to use higher-level cognitive skills or to discuss substantive scientific knowledge associated with investigations, and many of the tasks presented to them continue to follow a cookbook approach that concentrates on the development of lower-level skills and abilities.

The reviews discussed earlier in this chapter revealed a mismatch between the goals articulated for the school science laboratory and what students regularly do during those experiences. Ensuring that students' experiences in the laboratory are aligned with stated goals for learning demands that teachers explicitly link decisions regarding laboratory topics, activities, materials and teaching strategies to desired outcomes for students' learning. The body of past research suggests that far more attention to the crucial roles of the teacher and other sources of guidance during laboratory activities is required, and that researchers must also be diligent in examining the many variables that interact to influence the learning that occurs in the complex classroom laboratory.

Developing Inquiry and Learning Empowering Technologies

In the early 1980s, digital technologies became increasingly visible in school laboratories and were recognised as important tools in school science (Lunetta 1998). Much evidence now documents that using appropriate technologies in the school laboratory can enhance learning of important scientific ideas. Inquiry empowering technologies (Hofstein and Lunetta 2004) have been developed and adapted to assist students in gathering, organising, visualising, interpreting and reporting data. Some teachers and students also use new technology tools to gather data from multiple trials and over long time intervals (Dori et al. 2004; Friedler et al. 1990; Krajcik et al. 2000; Lunetta 1998). When teachers and students properly use inquiry-empowering technologies to gather and to analyse data, students have more time to observe, reflect and construct conceptual knowledge that underlies their laboratory experiences. Using appropriate technology tools can enable students to conduct, interpret and report more complete, accurate and interesting investigations. Carla Zembal-Saul et al. (2002) suggested that such tools can also provide media that support communication, student–student collaboration, the development of a community of inquirers in the laboratory classroom and beyond and the development of argumentation skills.

Two studies illustrate the potential effectiveness of particular technology in school science. Marry Nakleh and Joe Krajcik (1994) investigated how students' use of chemical indicators, pH meters and microcomputer-based laboratories (MBL) affected their understanding of acid-base reactions. Students who used computer tools in the laboratory were more able to draw relevant concept maps, describe the acid-base construct and argue about the probable causes of why their graphs formed as they did. Judy Dori et al. (2004) developed a high school chemistry unit in which students pursued chemistry investigations using integrated desktop computer probes. Using a pre-post design, these researchers found that students' experiences with the technology tools improved their ability to pose questions, use graphing skills and pursue scientific inquiry more generally. To sum up, there is some evidence that integrating information and communication technology (ICT) tools into the science laboratory is promising. However, this development is still at an early stage. The level at which ICT is used in laboratory classes varies a lot. We assume that, in the future, this will expand. In addition, it is expected that ICT will be used to achieve more integration between practical work and computer-based simulations. This is an area that needs more research regarding its educational effectiveness.

The Development of Metacognitive Skills in the Science Laboratory

As we have seen, the high hopes for developing thinking skills in the laboratory failed partly because of inadequate alignment of learning theories with school science practice. One factor that has brought new understanding to this area is *metacognition*, which refers to higher-order thinking skills that involve active control over the thinking processes involved in learning. Activities such as planning how to approach a given learning task, monitoring comprehension and evaluating progress towards the completion of a task are metacognitive in nature (Livingston 1997). There is no single definition used for metacognition and its diverse meanings are represented in the literature that deals with thinking skills. Gregory Schraw (1998), for example, presents a model in which metacognition includes the two main components: knowledge of cognition and regulation of cognition. Knowledge of cognition refers to what individuals know about their own cognition or about cognition in general. It includes at least three different kinds of metacognitive knowledge: declarative knowledge about oneself as a learner and about factors that influence one's performance (knowing 'about' things); procedural knowledge about doing things in terms of having heuristics and strategies (knowing 'how' to do things) and conditional knowledge about when to use declarative and procedural knowledge and why (knowing the 'why' and 'when' aspects of cognition). Regulation of cognition refers to a set of activities that help students to control their learning. Although a number of regulatory skills have been described in the literature, three essential skills are included in all accounts: planning involves the selection of appropriate strategies and the allocation of resources that affect performance; monitoring refers to one's online awareness of comprehension and task performance and evaluating refers to appraising the products and efficiency of one's learning. Other researchers such as John Baird and Richard White (1996) have made different divisions and categorisations of metacognition.

When applied to science learning generally, metacognition is related to meaningful learning, or learning with understanding (Baird and White 1996; Rickey and Stacy 2000; White and Mitchell 1994), which includes being able to apply what has been learnt in new contexts (Kuhn 2000). Metacognition is also related to developing *independent learners* (NRC 1996, 2005), who typically are aware of their knowledge and of the options to enlarge it. One key component is *control* of the problem-solving processes and the performance of other learning assignments. Researchers link this *control* to the student's *awareness* of his or her physical and cognitive actions during the performance of the tasks (Baird 1998; White 1998). Another element is the student's *monitoring* of knowledge (Rickey and Stacy 2000). Learners who properly monitor their knowledge can distinguish between the concepts that they know and the concepts that they do not know and can plan their learning effectively.

The link between metacognition and scientific inquiry seems to be obvious. Scientists depend on their ability to control reasoning when working out new ideas and weighing up the evidence confirming or contrasting these. Dianne Kuhn et al. (2000) argue that students who experience inquiry activities in a similar way 'come to understand that they are able to acquire knowledge they desire, in virtually any content domain, in ways that they can initiate, manage, and execute on their own, and that such knowledge is empowering' (p. 496).

Baird and White (1996) claim that four conditions are necessary in order to induce the personal development entailed in directing purposeful inquiry: time, opportunity, guidance and support. The science teacher should provide students with experiences, opportunities and the time to discuss their idea about the problems that they have to solve during the learning activity. The role of the teacher is to provide continuous guidance and support to ensure that students develop control and awareness over their learning. This can be accomplished by providing students with more freedom to select the subject of their project and to manage their time and their actions in the problem-solving process. The social learning perspectives described earlier also draw attention to the support that students might get from peers in the laboratory. Students can clarify their ideas and the way they had developed them, in order to explain those ideas to their classmates. Moreover, laboratory experiences in which students discuss ideas and make decisions can present many opportunities for teachers to observe students' thinking as they negotiate meaning with their peers. Carefully observing students' actions and listening to their dialogue creates opportunities for teachers to focus questions and make comments within learners' zones of proximal development (Duschl and Osborne 2002; Vygotsky 1978, 1986) that can help the students to *construct* understandings that is more compatible with the concepts of expert scientific communities.

An application of these perspectives is demonstrated in a chemistry laboratory programme titled Learning in the Chemistry Laboratory by the Inquiry Approach was developed by Hofstein et al. (2004) at the department of Science Teaching at the Weizmann Institute of Science in Israel. For this programme, about 100 inquiry-type experiments were developed and implemented in eleventh and twelfth grade chemistry classes in Israel. A two-phased teaching process was used, including a guided pre-inquiry phase followed by a more open-ended inquiry phase. Based on their research, Mira Kipnis and Avi Hofstein (2008) have linked metacognitive skills (based on the model of Schraw 1998) to various stages of the inquiry-oriented experiments. First, whilst asking questions and choosing an inquiry question, the students revealed their thoughts about the questions that were suggested by their partners and about their own questions. In this stage, *metacognitive declarative knowledge* is expressed. Second, whilst choosing the inquiry question, the students expressed their *metacognitive procedural knowledge* by choosing the question that leads to conclusions. Third, whilst performing their own experiment and planning changes and improvements, the students demonstrate the *planning* component of *regulation of cognition*. Fourth, at the final stage of the inquiry activity, when students write their reports and have to draw conclusions, they utilise *metacognitive conditional knowledge*. Fifth, during the whole activity, students made use of the *monitoring* and *evaluating* components concerned with *regulation of cognition.* In this way, they examined the results of their observations in order to decide whether the results are logical.

Scientific Argumentation and Epistemologies – A New Rationale for Practical Work

When Rosalind Driver et al. (2000) presented their introduction to argumentation in science education, they quickly pointed towards the relevance for practical work. They saw argumentation as correcting the misinterpretation of the scientific method that has dominated much of science teaching in general and practical work in particular. Rather than focusing on the stepwise series of actions carried out by scientists in experiments, they suggested a focus on the *epistemic practice* involved when developing and evaluating scientific knowledge. Gregory Kelly and Richard Duschl (2002) similarly present science learning as *epistemic apprenticeship*: the appropriation of practices associated with producing, communicating and evaluating knowledge. Within this framework, practical work becomes a way of introducing students to *community standards* applied by scientists. We sense two overlapping learning aims: students should understand the scientific standards and their guiding epistemologies; and students should be able to apply these standards in their own argumentation.

We find many ways of approaching research into students' epistemological understanding and argumentation skills. One contribution comes from psychologists who identify scientific argumentation as the key element of scientific thinking (Kuhn et al. 1988). Dianne Kuhn et al. work from the perspective that certain reasoning skills related to argumentation are domain general. People who are good at scientific argumentation are able to (1) think *about* a scientific theory, rather than just think *with* it; (2) encode and think about evidence and distinguish it from theory and (3) put aside their personal opinions about what is 'right' and rather weigh a theoretical claim against the evidence. Kuhn (2000) demonstrates how these abilities develop naturally from childhood to adulthood, but also that the quality varies amongst people. Scientists are good at this thinking because it is embedded in their culture and, importantly, explicit training in the science laboratory seems to help (Kuhn et al. 2000).

Another contribution comes from research on *procedural knowledge* (Gott and Duggan 1995) presented earlier in this chapter. Glen Aikenhead (2003) illustrates the relevance in society and work life of understanding issues related to the way in which scientists use data as evidence to draw conclusions. The underlying idea is that knowledge about data and the use of data developed in the laboratory can be transferred to these situations. One study of university students supports this (Roberts and Gott 2007), but little evidence yet exists for younger pupils.

Several research studies indicate that the development of students' argumentation skills and science epistemologies is rather complicated. Students, for example, might hold some beliefs about professional science and very different beliefs about their own practices with inquiry at school (i.e. students have one set of *formal* epistemologies and another set of *personal* epistemologies) (Hammer and Elby 2002; Sandoval 2005). Many years of teaching 'ideas and evidence' in the UK through practical investigations illustrate this complexity (Driver et al. 1996). Per Kind (2003) suggested that the overall picture has been that students become good at doing specific types of routine experiments, and solve these using school-based strategies rather than a general understanding of formal scientific epistemologies. Jim Ryder and John Leach (2005) assume that one reason for these problems is that learning objectives are not sufficiently made explicit to the students. Most students are able to articulate the learning objectives following a lesson focused on science content knowledge, even if they struggle to understand the concepts. However, when the objective of a lesson has an epistemological or procedural focus, students are much more unclear about what they are intended to learn.

Many writers have also related the problems with developing epistemological views and practices in school science to the teachers' background and competencies. Maher Hashweh (1996) has found connections between the epistemological beliefs expressed by teachers and their preferred ways of teaching, but the relationship is not simple. It is teachers with naïve epistemological beliefs who most easily support teaching 'real science' in the school laboratory. In addition, it is suggested by Nam-How Kang and Carolyn Wallace (2005) that such teachers more easily view students as 'young scientists' who are able to construct meanings on their own. For a teacher with a more sophisticated epistemological understanding of science, the relationship is more complicated. They tend to disconnect 'real science' from 'school science' and more rarely allow their epistemological beliefs to be reflected in their teaching practice, as shown in studies conducted by John Barnett and Derek Hodson (2001) and by Nam-How Kang and Caroline Wallace (2005). Teachers with sophisticated epistemologies also seem to separate science from students, treating students as more as 'spectators' of science (e.g. Randy Yerrick et al. 1998).

Pilar Jimenez-Aleixandre et al. (2000) suggested that a better understanding of how practical work might contribute towards the development of students' epistemological understanding and argumentation skills could involve a closer look at the 'teaching ecology' of the laboratory. It is strongly argued that bringing argumentation into science classrooms requires the enactment of contexts that transform them into knowledge-producing communities, which encourage dialogic discourse and various forms of cognitive, social and cultural interactions amongst learners (Duschl and Osborne 2002; Newton et al. 1999). An ecology that promotes this practice is created through the social and physical environment (Wolff-Michael Roth et al. 1999), the laboratory tasks (Clark Chinn and Betina Malhotra 2002) and the organisation principles used by the teacher (Issam Abi-El-Mona and Fouad Abd-El-Khalick 2006; Phil Scott 1998). A reconsideration of all these factors is therefore needed for the science laboratory to contribute meaningfully and effectively towards the new learning goals.

Concluding Remarks

The biggest challenge for practical work, historically and today, is to change the practice of 'manipulating equipment not ideas'. The typical laboratory experience in school science is a hands-on but not a minds-on activity. This problem is related to teachers' fear of loosing control in the classroom and giving students more responsibility for their learning. Also, the current situation can be blamed on assessment practices that do not pay enough attention to higher-order thinking and a long tradition of developing foolproof laboratory tasks that guide students through activities without requiring deep reflection. This chapter has demonstrated a relationship between these problems in practical work and commonsense ideas about science inquiry as a stepwise method.

It has taken science education research a long time to reveal this practice, analyse its underlying rationale and present alternatives. The development has required a move away from quantitative data-collection methods, which are not sensitive to students' learning in the laboratory, towards more authentic ways of studying what actually goes on in the laboratory. It has also required a thorough analysis of the nature of science inquiry and what makes someone good at doing it. The alternatives that are prominent today not only combine sociocultural perspectives on science and learning, but also link to new aims for school science as an important provider of skills and knowledge for citizenship.

At the turn of the century, we might claim that science education is in a better position than ever before for developing meaningful and appropriate practices for laboratory work. The situation is most promising because of the results and knowledge that have been accumulated and achieved. There are many places to start in developing new laboratory teaching strategies and professional development provisions for teachers. These and other tasks call for science education researchers to engage with practical work and to help to develop this area further.

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Chapter 16
From Teaching to KNOW to Learning to THINK in Science Education

Uri Zoller and Tami Levy Nahum

Introduction

The development of students' learning via higher-order cognitive skills (HOCS)-promoting teaching is a continuous overriding challenge for many educators and researchers in science education. This chapter focuses on the paradigm shift from the traditional lower-order cognitive skills (LOCS) rote-algorithmic teaching to know, to HOCS-promoting learning to think, while referring to the relevant multicomponents educational system of teaching strategies, learning styles and assessment methods.

Worldwide, a major driving force in the current effort to reform science education is the widely held conviction that it is vital for our students to develop their HOCS capacity, to enable them to actively function and meaningfully participate in the relevant decision-making processes operating in the context of the complex science-technology-environment-society (STES) interfaces of multicultural societies.

HOCS is conceptualized as a non-algorithmic, complex, multicomponent conceptual framework of reflective, reasonable, and rational systemic evaluative thinking, focusing on deciding what to believe and do, or not to do, to be followed by a responsible action (Zoller 1993, 2000).

In this chapter, we envision HOCS as an umbrella encompassing various overlapping and interwoven forms of cognitive capabilities (Fig. 16.1), such as critical thinking, system thinking, question-asking, evaluative thinking, decision making, problem solving and, most importantly, transfer. Thus, critical thinking (Ennis 2002) and lateral (system) thinking (de Bono 1976) involve uncertainty, application of

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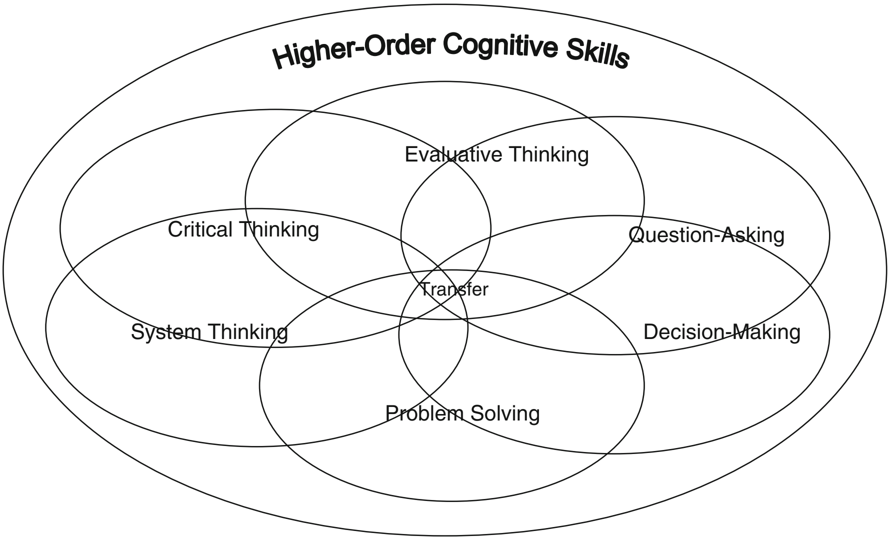

Fig. 16.1 The guiding conceptual model of HOCS in the context of science education

multiple criteria, reflection, and self-regulation (Resnick 1987), and these are all interwoven components within the HOCS framework.

Figure 16.1 illustrates schematically our complex conceptual model of HOCS, referring to interrelated generic (non-content-wise) cognitive capabilities, making sense in context. It is a nondirectional superordinate model, not specifically ordered or linearly hierarchical. The important LOCS components of basic cognitive capabilities are inherently embedded in the various components of the model and are not dealt with in this chapter.

In Bloom's taxonomy of cognitive development (Bloom et al. 1956), analysis, synthesis, and evaluation are considered as HOCS whereas recall of information, comprehension, and application are envisioned as LOCS. The HOCS conceptual model is different in its (1) being non-linearly ordered from bottom-up as far as the various capabilities and/or skills are concerned; (2) being not demanding, nor suggesting a particular hierarchy in the development or the acquirement of the HOCS components; and (3) being an overlapping synergistic collection of capabilities and skills such that linear progress from the bottom (knowledge) to the top (evaluation) should not, necessarily, be maintained in the learning process of individuals, nor should it be applied in this linear bottom-up mode by them.

We refer to the *Transfer* capability (Fig. 16.1), as the superordinate HOCS capability, required for "bringing home" the overriding objectives of HOCS learning in different situations and real-life problem-solving contexts. This suggests designing science teaching, assessment and learning as a challenging enterprise, purposed at promoting the capability to generate ideas and alternatives rather than just to select among given/known available alternatives (Zoller and Scholz 2004).

The main components of the HOCS framework are briefly presented and discussed, targeted at translating the HOCS model into a viable, applicable science teaching practice. In doing that, we shall avoid using definitions of HOCS key components, since definitions, by definition, are limiting rather than opening the scope for multidimensional interpretation and flexibility in the evolving teaching practices.

Critical Thinking

In our real world, people are more and more required to adequately respond to the complex problems they are confronted with, by making rational decisions, based on evaluative, critical system thinking, rather than to passively accept solutions provided, or imposed by others (people, authorities, or society at large). Therefore, the development of students' HOCS capabilities encourages them to raise doubts, investigate situations, and probe alternatives, in the context of both school and daily life (Zoller 1993, 1996).

Meeting such challenges requires the development of a student's capacity for *Critical Thinking* (Fig. 16.1), which is necessary for the in-depth analysis of unfamiliar situations, so that their related HOCS will be based on rational thinking (Ennis 2002; Barak et al. 2007). Indeed, critical thinking has been defined as the skill of taking responsibility and control of our own mind, or as logical and reflective thinking that focuses on a decision what to believe in and what to do (Zoller et al. 2000). It involves a variety of skills such as the identification of the source of the information, analyses of its credibility or bias, reflecting on whether this information is consistent with prior relevant knowledge and, ultimately the drawing of conclusions based on critical thinking (Linn 2000). This capability is considered to be essential for the promotion of metacognitive understanding (Kuhn 1999). It is conceptualized by us as result-oriented, rational, logical, and reflective evaluative thinking, in terms of what to accept (or reject) and what to believe in, followed by a decision what to do (or not to do) about it; then to act accordingly and to take responsibility for both the decisions made and their consequences (Zoller 1999).

Question-Asking

Question-asking is an essential component of the HOCS model, particularly in the context of the critical thinking problem-solving process. Therefore, the development of this capability should be an integral component within the teaching process (Dori and Hershkovitz 1999; Zoller 1993). This requires a purposed effort on the part of science teachers to encourage and challenge their students to ask relevant, in-context meaningful questions and, persistently, to exercise this capacity. The contemporary dominant practice of students conditioned just to provide a one correct answer without wait time to mostly algorithmic-type questions asked by the teacher or by the textbook, is leading, at best, to successful algorithmic-learning; that is, knowledge acquisition, not evaluative thinking capability (Tami Levy Nahum et al. 2010).

An examination where the student asks the questions is one of our proposed strategies to translate into practice the agreed upon objective of shifting from knowing to thinking (Zoller 1994). This unique assessment strategy, which has been longitudinally practiced and research evidenced, is described later in this chapter.

System Thinking

System or lateral thinking (de Bono 1976) is a key-cognitive component within the HOCS conceptual model that enables us to deal with our world's complex problems in their real context. Although it doesn't guarantee a single, unidimensional solution to the problem at point, it does enable deep and comprehensive dealing with the complexity of the problem and referring to different solutions. System thinking means the cognitive ability to see and consider the whole (system), the parts (sub-systems) of the whole, the mutual interrelationships between them (the dynamics and change intra-impact), and the overall mode of operation. Developing system thinking helps to perceive the importance of, and to meaningfully deal with, multidimensional complex phenomena and to consider the significant interdisciplinary relationships in the system. That is, system thinking offers us a cognitive tool that is broadening, expanding, and re-formulating our regular, simplistic way of thinking regarding complicated subjects. Therefore, developing system thinking in science education isn't only geared toward providing additional skill, but also for the crystallization of a comprehensive view point that would create a basis for the meaningful productive co-application of other HOCS (Zoller and Scholz 2004; Ben-Zvi Assaraf and Orion 2005).

Evaluative Thinking

In the broad context of science education, we conceptualize a learner who has acquired evaluative thinking capability as a self-reflective, doubting, and rational, who purposely applies critical system thinking, followed by an in-context decision concerning the course of action that should be taken, in order to resolve or relate to problem-solving situations and the entire spectrum of real-life issues (Levy Nahum et al. 2009). Within the HOCS conceptual framework, we consider evaluative thinking as a complex cognitive ability, encompassing/integrating the various overlapping components of other cognitive abilities such as critical system thinking, and creative judgments. We expect the evaluation process to be followed by a responsible decision of the evaluator as to what course of action has to be taken in order to resolve the issue at point.

Decision Making

As citizens in a modern world of conflicting interests, we should be able to use a whole spectrum of various multidimensional HOCS such as asking relevant meaningful questions and thinking systemically and critically, in order to make intelligent and rational decisions in dealing with solving personal, social, or scientific-technological problems (Facione and Facione 2007; Zoller and Tsaparlis 1997). It appears to be agreed upon that, in confronting complex issues within operating complex systems, science educators should focus in their science teaching on multifaceted issues, discuss their problematic components and, in this context, encourage students to develop and ultimately apply their HOCS practice throughout their related learning process. Equipped with these cognitive tools, students will, hopefully, be able to make rational decisions, and act accordingly. The key role of decision making in this context is straightforward (Levy Nahum et al. 2010).

Problem Solving

Problem (not exercise) solving is one of the most important human capabilities in our multicomponent, complex world. So, what do we mean by a problem? John Hayes (1981) suggested that, whenever there is a gap between where you are now and where you want to be but you don't know how to cross that gap, you have a problem.

Problems in science, in science education, or in any other discipline, come in many forms and styles and are presented in various modes and contexts. Alex Johnstone (1993) categorized problems according to three parameters: (1) whether or not data was given, (2) whether or not the method was familiar to the solver, and (3) whether or not the problem posed lead to a specific and well-defined solution/goal. Using this model, Johnstone identified several different types of problems ranging from a purely algorithmic task, to a task, which is not accompanied with given data, requires the application of unfamiliar (to the learner) methods, and has ill-defined characteristics. The former may be considered to be an exercise rather than a problem, while the latter is considered to be an open-ended problem, or simply a problem – as distinct from an exercise.

The use of additional context can make a problem or a science course more engaging for students, but it can also make it more complex. In such cases an individual's ability to "see the wood for the trees" and pull out relevant and useful information or hints from a complex situation could enhance their success in solving the problem (Overton and Potter 2008). Thus, problem-solving activities within HOCS-promoting teaching strategies may expect to promote HOCS learning, while exercise solving centered teaching may (but not necessarily so) result, at best, in algorithmic knowledge gain (Ben Chaim et al. submitted).

Transfer

As mentioned previously, in our view, the transfer capability is central in science education and highly essential for applying HOCS in different contexts and situations. It constitutes an effective way to measure conceptualization (Cohn 2005; Solomon and Perkins 1989). In fact, attaining the capacity of transfer within the domain and even more so – outside of the particular subject matter taught, is considered by the educational community to be the ultimate overriding goal of both science education and education at large (Zoller 2000). Training in the application of problem solving and decision making within a wide range of situations has been demonstrated via research, to promote transfer in new situations and contexts. The transfer is, therefore, advanced by exposing the learner to a wide variety of non-algorithmic tasks in different contexts, by experiencing a wide range of applications. Such experiences enable the learner to represent problems and ideas in their appropriate levels of abstraction and complexity, and to develop flexible representations and deep conceptualizations of what is learned. All of this, as an extension of the domain-specific situated cognition is to be encouraged by teachers and to be applied in their science teaching.

Learning Science in the Interdisciplinary STES Interfaces Context

Societies, worldwide, are continuously coping with sustainability related complex issues in the Science-Technology-Environment-Society (STES) interfaces' context. An interdisciplinary approach, accompanied by evaluative thinking has the potential of providing a balanced world outlook and a meaningful understanding of the different operating systems and their interrelationships. Thus, we suggest that if teachers purposely and persistently promote students' HOCS capabilities within interdisciplinary STES contexts in their classes, there is a solid research-based evidence of a good chance for a consequent positive development of the targeted capabilities, decision making, and problem solving included.

The implementation of science for all (American Association for the Advancement of Science (AAAS) 1989) in science education has been strongly advocated since the 1980s. As a result, massive efforts were invested and huge resources were allocated for the design of new science curricula (Tomorrow 98 1992). The fusion of the Science-Technology-Society (STS) movement (Yager 1993; Solomon and Aikenhead 1994) and environmental education for sustainability has yielded the STES orientation in science education (Zoller 1991, 2000). Seven such STES modules have been developed and implemented within a science curriculum. These modules, entitled *Science, Technology and Environment in Modern Society* (Zoller 1998) were developed by seven different teams of teachers in the schools. Each module was designed to serve as an effective STES-oriented curriculum unit, incorporating research-based HOCS-promoting teaching, learning, and assessment strategies. The ultimate goal was the conceptualization by students, of fundamental concepts in science; for example, reversible and irreversible processes, dynamic equilibrium, and periodicity (see also later sections in this chapter).

HOCS Development

From Theory to Practice

The literature in science education emphasizes the importance of promoting students' HOCS capabilities. It is well known, however, that even widely accepted educational theories (or reforms) are not as easily implemented in the classroom as originally planned (Barak et al. 2007). Consequently, there is a gap between educational guiding theories and the related goals to be attained through the developed and implemented curricula, teachers' professional development programs, and the actual practice implemented in the classroom (Boddy et al. 2003).

The translation of a LOCS-to-HOCS shift into practice in science education is inhibited by conflicting pressures and major systemic factors such as the traditional high-stakes assessment and grading systems in both in-class and external examinations (Lerry Nahum et al. 2007; Zoller 1999). Therefore, any progress toward the attainment of HOCS learning-related goals constitutes a great challenge in contemporary science education; that is, it would require the application of a new pedagogical approach, different from the teaching to know strategies and, most importantly, to constitute an alternative to the currently dominant, traditional assessment methodologies, within newly designed appropriate science curricula and courses that would mesh with the leading desired learning outcomes.

Pioneered by Uri Zoller's group and others (Leou et al. 2006; Overtone 2001), an extensive range/set of innovative research-based teaching and assessment strategies and methods complying with the HOCS conceptual model and its guiding objectives have been developed and implemented worldwide during the last two decades. Selected examples of these strategies, methods, exemplary HOCS-type questions, or tasks and tools are presented in the following sections.

Teaching Strategies and Assessment Methods for HOCS Development: How to Do It?

A crucial issue is how to translate the above into manageable and effective HOCS-oriented courses, teaching strategies, assessment methods, and HOCS-promoting examinations that will be in consonance with the desired HOCS-learning outcomes and be implemented by professionally prepared and conceptually converted teachers.

Traditional science teaching is based on textbooks presenting neat, clear-cut, authoritative, unchallenged theories, rules of nature, and ultimately one correct solution to each related problem posed (Nakhleh 1993). Typically, this line of teaching emphasizes formal definitions, equations, facts, formulas, and algorithms, in terms of knowing, remembering, defining, and identifying, all of which empower students to respond successfully to LOCS-requiring questions (Zoller and Tsaparlis 1997).

Because assessment constitutes an integral part of the teaching-learning process, HOCS-oriented science teaching requires the same orientation in assessment. Within efforts to promote science students' HOCS, we have incorporated a formative and summative-type practice-oriented research program targeting at finding to what extent and under what circumstances, HOCS learning is attainable (AAAS 1994; Zoller et al. 1999, 2002). In our view, one of the more important issues in science education and in education at large, at all levels, is the agreed-upon perception by educators and teachers of the teaching and assessment strategies as an integral entity. The whole attitude regarding these crucial factors should be significantly changed; specifically, examinations as well as other assessment means must not only be an integral part of the teaching process and aligned with the HOCS-learning goals, but also to meaningfully foster them as well as contribute to their promotion and attainment (Zoller 1990).

A shift from focusing on what should our students know in order to succeed in the examination, to what should our students be able to think, decide, resolve, do, or act, must be operationized. We suggest that our practice-oriented research efforts contribute to the application of this paradigm shift.

Teachers are generally acknowledged as the key figures in making any type of curriculum significantly different. Accordingly, we do expect the science teacher to be capable of designing her or his own curriculum and restructuring available curriculum suggestions, in accordance with her or his needs and aligned with the HOCS goals. Students should be guided by the science curriculum materials as well as their teachers, on how to develop these skills purposely and intelligently through persistent practice.

For successful pursuit of the above, teachers' pedagogies should include a few of the numerous possible ways of how to do it proficiently. Based on the findings of our longitudinal practice-oriented active research, a LOCS-to-HOCS paradigm shift in science/chemistry and STES education requires the purposeful implementation of teaching strategies (Zoller 1993, 2000), such as those presented in Fig. 16.2.

In the HOCS-learning context, a task is conceptualized as a problem type whenever the student is confronted with unfamiliar elements. Her or his engagement with such a novel component of the task is an effective means for the development of their related HOCS capabilities (Zoller and Tsaparlis 1997; Ben-Chaim et al. submitted).

Explaining ideas and interpreting information to someone else often requires the explainer to think about the problem in question in new ways, translating it in different terms, or generating new examples. These socio-cognitive activities induce the explainer to clarify related concepts, to elaborate on them, and to reconceptualize whatever is involved in some other manner. Thus, by actively interacting with peers

- Promoting an open and supportive atmosphere in the science classrooms
- Defining, explicitly, the course's and particularly the lesson's goal and objectives to enhance active participation of the students in the learning process
- Providing students with opportunities to explore
- Examine and consider different possible alternatives for resolutions when confronted with problems
- Encourage students to ask HOCS-type questions concerning the issues involved by fostering of in-class 'Question-Asking' and critical (evaluative) thinking
- No specific course textbook to be assigned; teach, learn and assess beyond the formal textbook framework
- Students cover/learn material *before* it is ‘covered’ by the instructor in class
- Lecture, recitation and lab sessions are integrated within the course
- Administration of specially designed HOCS- oriented examination
- Include students' learning materials (textbooks, notebooks, personal notes est.) in all examinations, take-home examination, oral or 'paper and pencil'-test
- Provide/use open HOCS-type, rather than multiple choice or true-false questions
- Provide and encourage explanations and foster argumentation skills rather than just relying on narrow-scope clear-cut definitions
- Focusing on problem, rather than exercise solving, should be 'the name of the game' in science education (Zoller et al. 1999)
- Cooperative learning environments can be an ideal setting for developing HOCS (Lazarowitz R., Hertz-Lazarowitz R., 1998).

Fig. 16.2 Selected teaching and assessment HOCS-oriented strategies

and teachers and having relevant information, students will be able to accomplish much deeper understanding rather than just memorizing the subject matter.

An innovative science teacher’s metacognition and HOCS-promoting professional development course, integrating formal and informal science and environmental education, was developed and implemented within a science teaching course, focusing on the leading role of HOCS in science education (Leou et al. 2006). The HOCS-promoting teaching and assessment strategies applied in this professional development course not only enabled participants to reflect on their own learning, but also facilitated their self-reflective metacognition-related assessment, utilizing a pre-post-designed research-based methodology. By reflecting on what has been done during the learning process, students are provided with the opportunity to develop their thinking skills within the context of science learning and, consequently, to be able to recognize the usefulness of these skills for practical purposes as well (Weinberger and Zohar 2000).

Our accompanying teaching practice-oriented research projects were based on the assumption that those traditional instructional strategies of teaching and assessment in science education are not compatible with the development and fostering of students’ HOCS. Our research findings corroborate this (Tal et al. 2001).

HOCS questions/tasks (Zoller and Tsaparlis 1997) are operationally defined as follows: HOCS problems are unfamiliar to the student and require for their solution, beyond knowledge and application, analysis and synthetic capabilities, as well as making connections and evaluative thinking on the part of the solver; this can include the application of known theories and HOCS to unfamiliar situations (transfer).

LOCS questions/tasks (Zoller and Tsaparlis 1997) are defined as follows: knowledge questions that require for their solution simple recall information or a simple application of known (to the student) theory or knowledge, to familiar situations and contexts; they can also be problems, solvable by means of algorithmic processes that are already known to the solver through specific directions or practice.

To this end (the development of students' HOCS), we have developed and validated appropriate teaching-assessment instruments. Selected examples of these cognitive tools are found in later sections.

An Action Model – The Decision-Making-Problem-Solving Act

A decision-making action model was developed and proposed to guide the science teaching of STES-oriented curricular modules in science education (Zoller 1990). It was later supported by the Mary Ratcliffe's (1997) model that described a similar framework based on other normative models. The Decision-Making-Problem-Solving Act model was successfully implemented in several curricular modules and courses (Tal et al. 2001). This model contains eight steps, not all are expected to be followed and not necessarily in the order given below in each case. Rather, it is suggested to be flexibly applied in alignment with each specific case, course, or curriculum:

1. Look at the problem and its implications, and recognize it as a problem.
2. Understand the factual core of knowledge and concepts involved.
3. Appreciate the significance and meaning of various alternative possible solutions (resolutions).
4. Exercise the Problem-Solving act:
   - Recognize/select the relevant data information
   - Analyze it for its reasonableness, reliability, and validity
   - Devise/plan appropriate procedures/strategies for future dealing with the problem(s), at point
5. Apply value judgments (and be prepared to defend!)
6. Apply the Decision-Making act:
   - Make a rational choice between available alternatives, or generate new options
   - Make a decision (or take a position)
7. Act according to the decision made.
8. Take responsibility!

HOCS-Promoting Questionnaires and Tasks

Questionnaires and tasks constitute an effective means for promoting the teaching-learning process, beyond just serving as assessment tools. We have developed several questionnaires for HOCS assessment and successfully used them in different

Read the following paragraph:

Resources and energy: What are the future options and alternatives?

Almost every aspect of the Western world is based on the consumption of energy and products derived from the finite crude oil and natural gas resources. There are sufficient reserves of coal that could lead to the production of enough synthetic fuel and gas for the present time. However, energy alternatives (e.g., solar, wind, tide, and waves) should be developed to satisfy the need for the production of electricity. This would involve the substitution of diminishing resources by available non-finite resources. Nuclear energy is another possibility. Future alternatives concerning resource exploitation and energy supply require an in-depth analysis and intelligent decision …and the sooner the better.

Four out of the 7 questions in this questionnaire are as follows:

1. Formulate three questions that you would like to, or think, are important to ask concerning the subjects dealt with in the paragraph.
2. Can you, based on the given paragraph (and the information it provides), decide on the desirable alternatives of energy supply in your country? Explain your answer.
3. *Formulate* two *criteria* that guides you (or will guide you) in your decision concerning the most desirable alternative.
4. Briefly explain the pros and cons of the alternative(s) that you have chosen with regard to future implications. Compare your alternative(s) with any other alternatives that you did *not* choose.

Fig. 16.3 The Decision Making Questionnaire

modes/formats and settings for promoting HOCS. An illustrative multicomponent STES-oriented HOCS questionnaire, with respect to decision making, is presented in Fig. 16.3 (Zoller and Scholz 2004).

Similarly, Evaluative Thinking questionnaires have been developed, designed, and validated (Levy Nahum et al. 2009). One focuses on Barbeque-Health-Ecology Interfaces and the other deals with Water-People-Environment.

Both have been content-wise and structurally validated by three experts in the field and showed a satisfactory inter-rater level. All these questionnaires were developed on the basis of the following: (1) the items posed have no right or wrong answer; namely, no item requires a single-dimension, one correct response; (2) they are linked to the STES context; and (3) they are associated with just first approximation relevant information, potentially useful for the respondents. Two of the twelve questionnaire's items are given below as examples:

Question 1. The title of the paragraph – Barbeque, Health and Ecology – includes ecology, although in the paragraph there is no mention of it. In your view, *are there any links* between barbeque and ecology? *Justify* your opinion in case you think that there are links and in case you think that there aren't.

Question 2. In your estimation, *what is the main aspect* that might have an impact on the future of people (or your) behavior concerning the discussed issue? *Justify* your evaluation.

The accumulated experience, accompanied by action research, suggests that the persistent implementation and practicing of HOCS-oriented teaching and assessment strategies is the key for the attainment of meaningful disciplinary and interdisciplinary generic HOCS learning (Levy Nahum et al. 2010).

Although the road to HOCS learning is rocky, this educational goal is attainable; it can and should (!) be done. Our longitudinal HOCS-related research suggests that only prolonged, consistent, and systemic persistence may advance students' HOCS capabilities (Ben-Chaim et al. submitted; Zoller & Pushkin 2007). In the next section, how to do it in chemistry teaching will be demonstrated.

HOCS Development: The Case of Chemistry Education

Traditional chemistry teaching has focused on the presentation of a sequence of definitions, equations, and facts to be memorized and the acquisition of algorithms to be applied or reproduced by students (Cracolice et al. 2008). Given this reality, the students' epistemological perspective on chemistry is one of receiving knowledge (Zoller 1993). Students do not really try to, and are not being challenged to, conceptualize the underlying key ideas (Levy Nahum et al. 2007). Commonly, students collect facts without applying judgments; they do not, and nor are they required to develop opinions. Chemistry knowledge is thus perceived as a rigid body of facts revealed by authority (professor or text) and the students' role is to return their rote-knowledge to these authorities, without processing it. Since students are not exposed to novel problems, their chemistry problem-solving skills as well as other relevant HOCS capabilities cannot be expected to be developed meaningfully (Zoller 1990; Zoller and Pushkin 2007).

The development of students' HOCS capacity in chemistry requires the use of appropriate teaching strategies such as inquiry-oriented class discussions, cooperative learning, and active participation of students in the teaching-learning-assessment processes (Zoller 1993). Such practices are useful when students are exposed to relevant real-world problem-solving/decision-making situations that require the application of their value judgment and critical thinking skills (Facione and Facione 2007). It also requires inquiry-oriented class discussions and open-ended HOCS-type examinations (Zoller 1991), rather than the traditional multiple choice objective tests (Nakhleh 1993).

The LOCS-to-HOCS Shift in Chemistry Education: How to Do It?

One of the several possible HOCS-promoting teaching strategies is an examination where the student asks the questions. From our long experience, this is the most successful teaching-learning strategy for translating HOCS-objectives into practice. This assessment strategy is innovative, oriented toward HOCS-promoting teaching/evaluation that has been ideated, developed, and successfully implemented, initially, within the teaching of chemistry to freshman science students (Zoller 1994).

The core element of such an examination in contradiction to the traditional pencil-and-paper class examinations (in which the students respond to a series of questions prepared by the teacher) is a pre-arranged in-class oral session, in which the course teacher or professor is examined by their students orally using their home preprepared written questions related to the course. Two to five of the student-formulated questions (which have not been treated during the class session) are selected by the teacher and redistributed to all course participants to serve as a take-home examination. Students respond individually to their pool-selected questions at home and return their responses to their professor for evaluation.

Obviously, this is only one of various possible alternative procedures for conducting examinations promoting HOCS. It definitely poses an intellectual challenge to students, leading to the application of students' self- and peer-assessment strategies in science education. Furthermore, if we engage students as partners in activities involving self-assessment or evaluation of their performance on tests and progress in learning, they can not only enhance their cognitive strengths and HOCS capabilities, but also learn in greater depth (Zoller et al. 1999). This means more time to be allocated for HOCS-promoting teaching that emphasizes the development and improvement of students' cognitive skills, mainly through their self-learning and active participation in the learning process. However, related difficulties such as time limitations and large classes associated with the design, administration, management and grading of HOCS-oriented homework and examinations, constitute a barrier for their implementation.

Class Discussions and Student Involvement

Class discussions initiated by the class teacher or the students, should present relevant problems and inquiry-type questions, rather than making just explanatory statements related to the course topics. In classes that never have experienced such a strategy, the following (or similar) responses are to be expected.

The following issue was presented by an organic chemistry professor to his sophomore class: "Which of the two, toluene or bromobenzene, would you expect to be more reactive toward electrophilic substitution, and why?… Let's think about it." The spontaneous response of one of the students was: "We are not supposed to think; you-the professors-are supposed to tell us the answer." The spontaneous responses of other students' on that occasion ("…do not venture off…teaching necessary for..[passing]..the final examination"; "…complete the reactions on the board … don't leave it for us all the time…") suggest that the teaching practice of traditional lecture-centered and LOCS-level final examination in chemical courses have already taken their heavy toll.

Figure 16.4 shows examples of questions that were used to initiate inquiry-oriented class discussions in an organic chemistry freshman course (Zoller 1999).

The point is that dispositions for HOCS thinking within the context of science/chemical education are contingent on provisions and opportunities to exercise and experience the related generic HOCS. Based on our experience, inquiry-oriented

1. Arrange pyridine, pyrrole, and imidazole in the order of their (a) water solubility, (b) capability of hydrogen bonds formation, (c) basicity, (d) nucleophilicity toward electrophilic (Lewis acid-catalyzed) substitution. Explain and rationalize your determinations.

2. The Aldol condensation presented above is a facile reaction which takes place under relatively mild conditions. (a) What is the driving force for this overall transformation? (b) Why is the base needed? (c) Why is the carbanion/enolate obtained during the reaction from the acetone and not from the benzaldehyde? (d) Can one obtain additional products in the given reaction? Explain your answers. (e) Is there any question(s) concerning the above that you might have? Formulate the question and try to briefly respond to it.

Fig. 16.4 Inquiry-oriented class discussions in an organic chemistry freshman course

BOTTLED mineral water can be a source of food poisoning responsible for thousands of cases of illness, according to new research. Scientists found that it could account for 12% of infections by the bug campylobacter, the biggest cause of food-borne infection in the Western world….The new research shows, for the first time, that bottled mineral water is a potential hazard. Bottled water was found to account for 12% of the cases studied, salad 21% and chicken 31%. Scientists compared 213 campylobacter cases with 1,144 patients… with stomach problems but were not infected with the bug. In Europe, legislation states that mineral water must be free from parasites and infectious organisms but, unlike tap water, it cannot be treated in anyway that may alter its chemical composition.

Fig. 16.5 Bottled water link to fatal food bug (The Scotsman/Craig Brown, Oct 2003)

class discussions (either in groups or in planar) constitute feasible and manageable teaching strategies that facilitate the synthesis between HOCS-oriented strategic knowledge and chemistry understanding.

The following question taken from a freshman general chemistry (Chem 1 type) midterm examination (Zoller et al. 1999) is an illustrative case study example of an intended HOCS-promoting examination question:

> Which, the atom or the ion, in each of the following three pairs: (P^+, P; Cl^-, Cl; and Br^-, Br) do you expect to have the *lower ionization potential*? *Explain* your ordering.

As a second illustrative case study, two LOCS questions versus two HOCS questions, based on the framed recent online e-mail publication (Fig. 16.5) are given in Table 16.1. We suggest that these and/or similar HOCS-type questions could be incorporated in homework assignments, midterm examinations in freshman as well as in high school chemistry courses within HOCS-oriented science education (Zoller 2004).

Selected illustrative HOCS versus LOCS problems are provided in Fig. 16.6.

The above problems related to real-life scenarios, situations, issues, and questions posed are unfamiliar to students in science/chemistry courses. Responding to such questions requires much beyond just basic knowledge (LOCS-type) that students are usually exposed to in general chemistry courses. The most meaningful aspects here are: (1) the required students' HOCS-level responses to those HOCS questions, (2) their making connections, and (3) their critically evaluating options concerning

Table 16.1 Illustrative LOCS vs. HOCS-Requiring Questions

LOCS-type questions	HOCS-type questions
According to the article: Is the higher mineral content of the bottled water (compared to "ordinary" tap water) – responsible for the higher health risk of the former?	Suggest a *controlled experiment* in the lab, via which you'll be able to unequivocally determine, that the difference in the "minerals content" between bottled and tap water is *not* responsible for the difference in their relative health risk
The disinfection of bottles used in the food industry is being done by Cl_2 (gas) in basic aqueous solution. Write the reaction mechanism in this oxidation process. Which is the *active* specie?	Assuming that the reported research has been conducted properly and the presented data are reliable and valid; what, in your opinion, is *the reason* for the poisonous potential of bottled water? Justify your conclusion

In a battery factory, workers are exposed to ZnS and $CdCl_2$ *(in the manufacturing of electrodes), HCl (in the preparation of the electrolytic bridge); oily grease (from oily metal parts);* CH_2Cl_2 *(a solvent for cleaning the grease); and* H_2S*. A suggestion was made to replace the water by petroleum for washing the workers' working clothes.*

1.1 Do you think that the idea of replacing the water with petroleum is good from the point of view of cleaning the cloth? Explain (Question level: HOCS).

1.2 What is the possible source of the (poisonous) H_2S in the battery factory? Explain and write the relevant chemical equation (Question level: LOCS).

1.3 Based on the chemistry that you know, propose a simple practical method to overcome the H_2S problem in the factory (Question level: LOCS+).

1.4 Do you think that the idea of replacing the water with petroleum is good from the point of view of the environment outside the factory? Explain (Question level: HOCS).

Fig. 16.6 Exemplary HOCS versus LOCS questions

the decisions to be made based on their thinking and conceptualization beyond the LOCS level (Ben-Chaim et al. submitted).

Additional illustrative examples of LOCS- and HOCS-level questions actually applied within a mid/final chemistry examination for freshman science students are presented in Fig. 16.7.

The difference between the two sample multi-item HOCS- and LOCS-level examination questions is apparent. Because the ultimate objective of HOCS-oriented teaching in contexts of science teaching is the development of students' HOCS, the way to advance in this direction is to shift from the merely formal presentation of a sequence of equations, facts, or algorithms.

Rocket fuels [HOCS-level problems]

Different fuels are used for different purposes and applications. Fuels, which are used in rockets, are dimethyl hydrazine $C_2H_8N_2$ and hydrogen according to the following reactions:

(1) $C_2H_8N_2 + 2N_2O_4 \rightarrow 3N_2 + 4H_2O + 2CO_2$

(2) $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(g)}$

a) Choose one of these two reactions and explain: what, do you think, are the main considerations in choosing this reaction as an energy source?

b) Why, in your opinion, N_2O_4 is used in reaction 1 instead of oxygen? Explain.

The emphasis in, and importance of, the questions above is not their level of difficulty but, rather, the HOCS level required for meaningfully dealing with them.

Buffer Solution [LOCS-level questions]

At your disposal is H_3PO_4 0.1M. You are to prepare, by adding sodium hydroxide, a buffer solution for PH=7. (Dissociation constants of Phosphoric acid are provided).

a) What are the concentrations of the main ions of the phosphoric acid in the buffer solution? Accompany your response with appropriate explanation and calculation.

b) If $Ca(NO_3)_2$ (a readily soluble salt) will be introduced into the solution that you have prepared, in a concentration of 10^{-3}M, would the salt $Ca_3(PO_4)_2$ precipitate? The Ksp of the Calcium Phosphate is $2.1x10^{-33}$. In your response to this question be helped by appropriate explanation and calculation.

Fig. 16.7 Examination questions for freshman science students

Students' Reflections Within HOCS Development

Students' appreciation of HOCS-oriented teaching within the study (Zoller 1999) is evident from the students' comments on the official evaluation questionnaires that were administered at the end of HOCS-promoting courses. In their words, "You (the teacher) have helped me to analyze problems and to use common sense to understand them, rather than simply memorizing a whole bunch of examinations…", or "I have benefited immensely from the emphasis on understanding rather than memorizing the material. However, I wish that this [i.e., understanding rather than rote learning] were reflected in final examinations"; and "… instead of spoon feeding us, you made us think—good!" . . . "I like to think that this is the way the doctors we trust for our health learned"; and "I appreciate your attitude of wanting us to really understand the material instead of just memorize it . . .".

The following quotes illustrate the participants' struggles along the traditional LOCS to the nontraditional HOCS assessment trail (Leou et al. 2006)

> This course began with a questionnaire which was the beginning of my journey of formulating questions and generating explanations for various situations using HOCS. This questionnaire exposed me to the practice of question-asking, problem solving, and the conceptualization of fundamental concepts. (p. 76)

The ultimate objective of HOCS-oriented teaching in the contexts of chemistry (science) and real-life situations is the development of students' HOCS, not their preparation for the LOCS-type final examination. Therefore, teaching strategies require venturing from the merely formal presentation of a sequence of equations, facts, and algorithms. It also requires, among others, social interaction among active participants within problem-solving situations (Zoller 1990, 1991).

In science/chemistry contemporary teaching, HOCS are usually developed and practiced within specific disciplinary areas, thus being subject matter-focused. Yet, their nature is generic not content-dependent. Therefore, their implementation in different contexts, should be worked out while taking care of the relevant constraints, and thus promote the transfer of these HOCS skills.

Although HOCS are not content-dependent, they are context-dependent. So, if acquired in a chemistry class, they do not transfer automatically to HOCS-promoting courses of other subject matter. Factors that affect the generalizability and transferability of cognitive thinking skills include understanding when a particular skill may be useful, capability of modifying the skill to fit different settings and contents, having the opportunity to practice with new material and to operate within new settings, and believing that a particular/relevant skill will be useful within new contexts or setting (Salomon and Perkins 1989).

Main Research-Based Findings and Insights

Our research supports the efforts being made worldwide, to implement HOCS-promoting teaching strategies/pedagogies in the science classrooms. Our studies reflect upon the importance of translating research findings into applicable teaching strategies for the development of students' HOCS capabilities and thus strengthen their conceptual understanding of science with all the implications involved.

Thus:

1. HOCS-promoting curricula, teaching materials, strategies, and in accord assessment tools are to be developed and implemented to endow our students with more than just algorithmic level in science learning.

2. Attaining STES-oriented chemistry literacy by students, requires an interdisciplinary systemic HOCS promoting approach in science teaching, targeting at evaluative HOCS learning for transfer.
3. Goals and expected outcomes of STES-oriented science course/program should be predetermined, to be followed by an appropriate, in accord, HOCS-promoting teaching assessment and learning practice.
4. Science/chemical education for sustainability should be an imperative within science education, at all levels.

Summary and Implications for Future Promotion of HOCS in Science Education

An important challenge for contemporary science education at all levels is the development and implementation of instructional practices that will foster students' HOCS capabilities of solving interdisciplinary, ill-structured complex problems. Our longitudinal research and implemented practice provide some fundamental insights into the way HOCS-type problems should be treated within science/chemistry teaching and assessment. The implications of these studies are as follows:

1. Problems (not exercises), which are integrated in HOCS-type homework assignments and examinations within the learning process, have the potential of developing students' problem-solving capability, because problems have the potential of eliciting HOCS-level responses on the part of the students.
2. The same applies to the other HOCS capabilities – system critical thinking, question-asking, decision making, and evaluative thinking. Continuously and persistently exposing students to the corresponding HOCS-promoting practice, accompanied by encouragement and support, does improve their overall HOCS capability and self-confidence in this mode of learning to think.

Because traditional science/chemistry teaching was shown by research to result in mainly LOCS level gain, the persistent integration of HOCS-promoting teaching, targeting at learning to think, will not only challenge students, but also will contribute, meaningfully, to the LOCS-to-HOCS paradigm shift as is evidenced by research. We have presented how to do it, providing a methodology for the design, development, application, and assessment of HOCS-oriented learning implemented within HOCS-promoting science teaching.

All of the above reflects the importance of translating research into applicable and manageable instructional HOCS-promoting strategies, thus strengthening students' conceptualization of science/chemistry fundamental principles and their capabilities of transfer in these and other scholarly and life domains. Because we strongly believe that students' HOCS development should be a prime instructional goal in science teaching, we recommend that HOCS-promoting examinations (including high-stakes examinations) should become an integral part of the teaching and learning process and meaningfully contribute toward the attainment of the

HOCS learning goal. We, the authors, believe that this goal can and should be achieved. Further research purposed at promoting this paradigm shift, and "how to do it" in different settings and contexts of our multicultural societies, will continue to be an issue of concern in science education research and teaching.

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Chapter 17
The Heterogeneity of Discourse in Science Classrooms: The Conceptual Profile Approach

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Classrooms are peculiarly complicated social places with one teacher trying to interact with maybe 30 to 40 students in order to support them in developing particular points of view. In the case of science teaching, such views include a meaningful understanding of science concepts. With so many individuals ostensibly engaged in a single event, it is hardly surprising that students and teacher display a range of understandings. In any classroom, there is an inevitable heterogeneity in talking and thinking, which will be the focus of this chapter.

First of all, we pose the question 'What is a concept?' and argue for a perspective that sees conceptualization as a process and concepts as being actualized when they are put to use. At the same time we propose that conceptualization has a permanence associated with it and develop this point by making a distinction between sense and meaning and by referring to the literature on memory. This takes us to the heart of the chapter, where we discuss conceptual profiles as a way of characterizing the heterogeneity of modes of thinking in the classroom. Finally, we explore how conceptual profiles can be used as tools in analyzing the discourse of science classrooms, thereby making the link between talking and thinking.

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What Is a Concept?

Concepts are treated in the science education literature in two different ways. A common approach is to view concepts as learners' mental models or schemes of an object or event. In this view, learners are treated as having concepts in their minds. This implies that concepts are relatively stable mental entities and are possessed by, or belong to, an individual.

The second perspective on concepts is quite different. It conceives concepts as something that only exist in a Popperian third world (Popper 1978; Wells 2008), as part of either a natural language or structured system of knowledge, such as science. Karl Popper (1972, 1978) referred to concepts as third world objects, distinguishing World 3 from the other two worlds in his model: World 1, the physical universe, and World 2, the world of conscious experience. Thus, Popper differentiates knowledge in the objective sense, which belongs to World 3 and exists in texts and language, from knowledge in the subjective sense, which belongs to World 2, and assumes the form of thought processes, related in turn to brain processes, which belong to World 1. What occurs in the mind of the individual, as part of the Popperian second world (Wells 2008), is not an instance of a concept, but a dynamic process, conceptualization, or in Lev Vygotsky's terms, conceptual thinking. Conceptualization is brought into play through an interaction between the individual and some external event or experience, and the process of conceptualizing is, in this respect, always social in nature.

From this point of view, concepts are not internal, more or less stabilized things, nor are they mental structures (Vosniadou 2008b) that are read aloud when an individual uses them. Nevertheless, there is an aspect of permanence in the process of conceptualization, that is, when conceptual thinking is fully developed, in a Vygotskian sense, it tends to operate in a similar manner in the face of experiences we perceive as being similar. It is this permanence – as a product of our enculturation – that allows us to both think through concepts and communicate with them effectively.

To elaborate on what is permanent in conceptualization, we will appeal to the distinction between sense and meaning (Vygotsky 1987). Vygotsky explains sense as follows: "A word's sense is the aggregate of all psychological facts that arise in our consciousness as a result of the word. Sense is a dynamic, fluid, and complex formation which has several zones that vary in their stability … In different contexts, a word's sense changes" (Vygotsky 1987, pp. 275–276). In turn, according to Vygotsky, meaning is stable and repeatable, offering the possibility of intersubjectivity, that is, the sharing of the meaning of a word by two or more people, despite the variation in the senses they attribute to it. Vygotsky also assumes that all concepts are generalizations. This explains why a particular word for a young child can signify differently than the same word for an adult. The word for the child is not yet a generalization; it does not have meaning, only a range of senses. As the child grows up, she undergoes a process of enculturation in which she faces many social situations in which she uses the same word, and it is through this social process that the word gradually acquires a generalizable, stable meaning. From this perspective the meaning of the word can never be something purely internal to a person; rather, it is a social construct in the sense of being socially developed.

For words belonging to everyday language, which have concrete referents, like table or dog, this process leads to relatively stable meanings, although these words are open to a variety of senses (such as referring to somebody as a 'dog'). This stability is a consequence of the social nature of conceptualization. It is because in language we have the word dog for referring to several carnivorous mammals of the family Canidae that the concept dog acquires this stability in individuals' conceptual thinking. But for scientific concepts, things are more complicated and we should read the texts of science before going to a university class and teach something like thermodynamics. If you go to this class without any preparation you will find yourself in difficulties, since some of the things that are perfectly clear in the book might not be in the same state in your mind.

From a Vygotskian perspective, therefore, conceptual thinking is an emergent process, resulting from the socially and culturally situated interactions between an individual and her experiences. Concepts are actualized when they are put to use. From this idea, it follows that heterogeneity in the nature of the socially and culturally situated experience can be translated into heterogeneity in conceptual thinking.

That is, a concept does not exist prior to the individual speech act that actualizes it. What is internal is thinking and memory, both assumed as processes, not as products. The literature on memory describes two subjective states of awareness associated with memory: remembering and knowing. Remembering refers to intensely personal experiences of the past, in which we seem to be reliving previous events and experiences mentally, while knowing refers to other experiences of the past, in which we are aware of knowledge we possess but in a more impersonal way (Gardiner and Richardson-Klavehn 2000).

These two subjective states of awareness are related to two different memory systems: episodic and semantic memory. Episodic memory refers to personal events and spatiotemporal relations among those events; semantic memory refers to knowledge possessed about words and other verbal symbols, their meaning and referents, the relations between them, and the rules and algorithms for the manipulation of symbols, concepts, and relations (Tulving 1983). Encoding in these two systems is assumed to be serial, in the sense that events have to be first encoded into semantic memory and then encoded into episodic memory (Tulving 1994). Before we can think conceptually about an event encoded into episodic memory, we should master the meaning of this concept as a social construction, encoding it into semantic memory.

The distinction between semantic and episodic memory can contribute to clarifying the interplay between the dynamic process of conceptualization, through which the sense of a word emerges, and the more stable, socially constructed meanings of words. When we think about an event, we conceptualize it in a particular manner, attributing specific senses to the words we use. However, there is some stability in the way we understand these words, since meaning, as a social construct, constrains the range of senses we ascribe to a given word. In this sense, a memory of an event, just as the sense of a word, is always dynamically constructed during the process of recall. When we recall and use a concept several times, we have the impression of having it, since it becomes very familiar to us. Nonetheless, recall is always a process in which we reconstruct the semantic memory and, often, also the episodic memory related to the concept.

To summarize, in the first approach to concepts, individual conceptualizations and concepts are treated as one and the same thing. This position tends to elide the Popperian distinction between the third and the second worlds. In this position, concepts are treated as having an enduring existence, independently of the context of use, due to their more or less fixed internal structures. These two characteristics of concepts – a concept as an internal artifact, with a decontextualized nature – are shared by most of the authors in the conceptual change movement, such as Stella Vosniadou, Xenia Vamvakoussi, and Irini Skopeliti (2008), and some other chapters in the *International Handbook of Research on Conceptual Change* (Vosniadou 2008a).

According to the second position, concepts and conceptualizations are distinguished and we can develop different ways of conceptualizing objects and events depending on the context. The conceptual profile approach is congruent with this latter view.

The Conceptual Profile Approach

Several authors have argued that people can have different ways of seeing and conceptualizing the world (e.g., Schutz 1967; Tulviste 1991). It can be argued, however, that the concepts and categories available in all the spheres of the world are held in an essentially similar form by a number of individuals, in such a manner that effective communication become possible. These collective representations (Durkheim 1972) are supra-individual in nature and are imposed upon individual cognition. When Vygotsky pointed to the social dimension of human mental processes, he was drawing from this position (Kozulin 1990). According to his famous general genetic law of cultural development, "any function in the child's cultural development appears twice, or on two planes. First it appears on the social plane, and then on the psychological plane. First it appears between people as an interpsychological category, and then within the child as an intrapsychological category" (Vygotsky 1978, p. 163). In these terms, individual thinking develops through the appropriation of cultural tools made available by means of social interactions. From this process of appropriation, it follows that we all share concepts and categories that can be used to signify the world of our experiences, but, since they are also constituted through our experience, the weight each of them has in our personal profile fundamentally depends on the extent to which they have been fruitfully used throughout our development.

The idea of a conceptual profile – that people can exhibit different ways of seeing and representing the world, which are used in different contexts – was proposed in the 1990s (Mortimer 1995), inspired by Bachelard's (1968) epistemological profile, even though its philosophical bases have substantially moved away from Bachelard's ideas in subsequent years. The conceptual profile approach was first proposed as an alternative to conceptual change theory (Posner et al. 1982) and is aligned with criticisms from other perspectives, such as William Cobern's (1996) contextual constructivism.

The conceptual profile approach is grounded in the idea of heterogeneity of thinking, that is, that in any culture and in any individual there exists not one homogeneous form of thinking, but different types of verbal thinking (Tulviste 1991). Conceptual profiles can be seen as attempts to model the heterogeneity of modes of thinking available for people with a given cultural background to use in a variety of contexts or domains (Mortimer 1995, 2000). Modes of thinking are treated here as the aspects of permanence in subjects' conceptual thinking, and, thus, are related to the socially constructed meanings attributed to concepts.

Conceptual profiles are built for a given concept and are constituted by several zones, each representing a particular mode of thinking about that concept, related to a particular way of speaking. Each individual has his or her own individual conceptual profile, as shown by the different weighting each zone exhibits in that particular profile. These differences depend on the individual's experience, which offers more or less opportunities for applying each zone in its appropriate contexts. For example, consider the concept of mass. The empiricist notion of mass, as something that can be determined with a scale, has a bigger weighting in the profile of a chemist who works daily in a chemical laboratory weighing samples than a rational notion of mass as the relationship between force and acceleration. The opposite holds true for a physics teacher who teaches Newton's laws every year to several classes. But notice that, according to the conceptual profile approach, it is only the relative importance of zones that varies from person to person. The zones or modes of thinking themselves are shared by individuals in a society, as maintained by sociocultural approaches to human action.

Assuming the existence of conceptual profiles as a manifestation of heterogeneity of thinking implies recognizing the coexistence of two or more meanings for the same word or concept, which are accessed and used by the individual in the appropriate contexts. Science itself is not a homogeneous form of knowing and speaking, and can provide multiple ways of seeing the world, which can coexist in the same individual, and be drawn upon in different contexts. For example, the concept of the atom is not restricted to one unique point of view. When explaining several properties of substances, chemists deal with the atom as a rigid and indivisible sphere, like the Daltonian atom. This model is not suitable, however, for explaining several phenomena, such as chemical reactivity, where more sophisticated models, including those derived from quantum mechanics, are used. Furthermore, it is not only in science that we find heterogeneity of thinking. Countless scientific words are also used in everyday language and, consequently, show several meanings other than those compatible with scientific points of view. In a conceptual profile, this means that one or more modes of thinking that are not compatible with the scientific ones will be present.

In the face of this heterogeneity, what does it mean to learn about atoms at school? We argued above that the different meanings of a concept, modeled as zones in a conceptual profile, can be accessed in appropriate contexts. Nevertheless, there is no guarantee that an individual does indeed work with appropriate meanings from the relevant zone. This is something to be learnt, and to learn this is to learn about the very heterogeneity of thinking and speaking and the diversity of contexts in which we use our thoughts and speech.

Accordingly, the conceptual profile approach conceives learning as involving two interwoven processes: (1) enriching an individual's conceptual profile, and (2) becoming aware of the multiplicity of modes of thinking that constitutes a profile as well as of the contexts in which they can be applied (El-Hani and Mortimer 2007). In science teaching, the first process typically involves learning scientific modes of thinking which students generally do not have access to by other means. In the second process, it is necessary to give the students a clear view about which modes of thinking are appropriate for which contexts.

For example, a student can become aware that the scientific concept of heat or heating, as a process of energy transfer between systems at different temperatures, is complementary to her everyday concept of heat, which assumes heat as being substantive in nature and proportional to temperature. If the notions are complementary, there are contexts in which one of the concepts is more appropriately used than the other. In the science classroom, students should learn the scientific concept. But the pragmatic value of everyday language will preserve meanings that are at odds with the scientific view. For example, to ask in a shop for a warm woolen coat is far more appropriate than asking for a coat made from a good thermal insulator. But if the students know that this warmth of the wool is in fact due to the warmth of our body as the wool only isolates it from the environment, they will show a conscious awareness of this profile, being capable of drawing on everyday and scientific ideas of heat in a complementary way.

Thus, learning involves not only understanding the scientific modes of thinking. Since students are not directed to break away from the other modes of thinking they use, which, albeit being nonscientific, play a role in their interpretation of experience, it is also a crucial learning goal that students become aware of the heterogeneity of modes of thinking and the demarcation between the contexts or domains in which each mode of thinking shows pragmatic power. To become aware of a multiplicity of meanings and contexts involves a dialog between new and old zones in a conceptual profile. Any true understanding, or meaning making, is dialogic in nature because we lay down a set of our own answering words for each word of an utterance we are in the process of understanding (Voloshinov 1973, p. 102). The conceptual profile approach thus also entails a Bakhtinian approach to understanding. From this perspective, understanding demands that we populate the discourse of others with our own counter-words. In these terms, a student will only be able to understand and learn scientific ideas by negotiating their meanings within her conceptual ecology, usually organized around nonscientific views.

In these terms, the relationship between scientific and everyday meanings for the same words is not one of subsuming all other forms of knowledge into science, but rather of developing dialogs between forms of knowledge in order to distinguish clearly between them and among the contexts in which they can be best applied. In this sense, nonscientific modes of thinking and meaning making are not treated as inferior, but as culturally adequate for some but not all spheres of life in which we act and talk. This also entails that scientific views are indeed more adequate in a number of spheres of life, and, for this reason, should be mastered by students if science education is to socially and culturally empower them. Moreover, it is not that one should necessarily avoid being critical about commonsense and other culturally based views, but rather that one is entitled to restrict the validity of these criticisms to the domain in which science is valid. In criticizing, for instance, the commonsense view that heat is proportional to temperature and is the opposite of another form of heat called cold, a teacher should insist that this latter view is different from the scientific one. She should also recognize that it can be more convenient to speak about cold and hot things in everyday life, since this approach has a deep cultural root, is part of our language, and allows for communication in most everyday situations. Nevertheless, in other everyday life situations, the scientific view of heat as a process of energy transfer is far more powerful than the commonsense view of heat and cold as properties of materials. Consider, for example, a situation in which one has to decide which type of drinking vessel will be better to keep a drink cold on a warm day, one made of aluminum or one made of glass. The commonsense view might lead us to choose the aluminum, since it is cold. The scientific view, on the other hand, helps us to understand that since aluminum is a better thermal conductor than glass (and therefore feels cold to the touch), the drink will get warmer quicker in the aluminum vessel than in the glass. In this sense, the conceptual profile approach helps us to comprehend how a student can come to apply a scientific idea in some but not all contexts of her daily life. If we help a student to become aware of her profile of meanings ascribed to a given concept, after learning the scientific view, she can comprehend in which contexts of daily life scientific views might best be applied.

Conceptual Profiles and the Analysis of Classroom Discourse

Several studies have highlighted the importance of investigating classroom discourse and other rhetorical devices in science education (e.g., Lemke 1990; Roth 2005). This new direction for science education research (Duit and Treagust 1998) signals a move away from studies focusing on individual students' understanding of specific phenomena toward research into the ways in which understandings are developed in the social context of the science classroom. Following a Vygotskian research tradition, more emphasis has been given to the role of social mediation, through language and other socially constructed symbolic systems, in meaning making in the instructional context of the science classroom (Mortimer and Smolka 2001; Mortimer and Scott 2003). In this section, we consider how the conceptual profile approach fits into an analysis of classroom discourse.

Discourse is quite generally conceived as a social phenomenon (van Dijk 1997). According to van Dijk, to characterize discourse in this broader perspective we should conceive it as a "socially situated communicative event" (p. 2), in which people verbally interact in order to communicate ideas and beliefs, or to express emotions. Thus, the integrated description of three dimensions of discourse is usually taken as a research goal: (1) language use – a linguistic phenomenon; (2) the communication of beliefs and ideas – a cognitive phenomenon; and (3) interaction in social contexts – a social phenomenon.

Mortimer (2001) suggests that the production of new meanings in the classroom can be investigated through a discourse analysis structured around the relationship between modes of thinking and ways of speaking. Conceptual profiles (Mortimer 1995 1998) are a heuristically powerful tool to analyze modes of thinking, that is, the cognitive dimension of discourse, while ways of speaking can be characterized in terms of Mikhail Bakhtin's (1981, 1986) social language and speech genres. Since it is only the relative importance of shared modes of thinking that varies from individual to individual, we need a tool to analyze these more stable modes of thinking amidst the conceptualizations that emerge in discursive interactions in the classroom. Conceptual profiles can be used as such a tool in discourse analysis.

Since conceptual profiles are constituted by zones representing modes of thinking and ways of speaking shared by individuals in a society, to build a conceptual profile, one should consider a diversity of meanings attributed to a concept and a variety of contexts of meaning making, encompassing at least three of the four genetic domains considered by Vygotsky, namely, the sociocultural, ontogenetic, and microgenetic domains (Wertsch 1985).

In order to establish the zones in a conceptual profile, one should consider data from several sources, not in a linear, but in a dialogic manner, in the sense that all sets of data are at the same time in interaction with each other. The following sources can be used: (1) secondary sources about the history of science and epistemological works about the concept at stake, which helps in understanding its sociocultural development; (2) literature on students' alternative conceptions about the concept, which are useful to investigate the ontogenetic domain; and (3), original data gathered by means of interviews, questionnaires, and video recording of discursive interactions in a variety of contexts of meaning making, particularly in educational settings, in order to investigate the ontogenetic and microgenetic domains.

It is important to clarify that the construction of the zones of a conceptual profile goes beyond categorizing extracts of data (although it typically involves this step), since the zones of a profile are signified by means of epistemological and ontological commitments that structure different modes of thinking about the concept at stake, and often are not explicitly given in utterances or statements. Moreover, a conceptual profile is intended to represent possible genetic routes for the development of different meanings of a concept. Thus, the commitments characterizing the zones should be seen from a dynamic perspective, as both posing limits and creating possibilities for meaning making. They not only bring difficulties to the construction of new meanings, but also hold the seeds for changes in signification.

For analyzing classroom discourse taking conceptual profiles into account, we use a framework proposed by Mortimer and Scott (2003). Following Vygotskian principles, we consider that science teaching entails a kind of public performance on the social plane of the classroom. This performance is directed by the teacher, who has planned the script for the performance and takes the lead in staging the various activities of the science lessons (Leach and Scott 2002). Central to the teaching performance is the job of developing the scientific story on the social plane of the classroom (Ogborn et al. 1996) and the support given to students in understanding scientific ideas. Of course, the teacher cannot exert absolute control over the ways in which the interactions are played out with students in the classroom (Candela 1999; Erickson 1982) and, consequently, the teaching and learning performance may develop along unexpected pathways.

Mortimer and Scott's framework was developed to analyze the speech genre of science classrooms and, in particular, the ways in which science teachers act to guide meaning making interactions on the social plane of high school classrooms. The framework is the product of an ongoing research program conducted over a number of years (Mortimer and Scott 2000; Scott 1998) and a detailed description of its development is set out elsewhere (Mortimer and Scott 2003). It is based on a sociocultural perspective on human action, just as the conceptual profile approach, and has been developed through a series of detailed case studies.

Central to the framework is the concept of communicative approach, which provides a perspective on how the teacher works with students to develop ideas in the classroom. The distinction between authoritative and dialogic functions, which is at the core of the communicative approach, is based on the notions of authoritative and internally persuasive discourse (Bakhtin 1981), and on the functional dualism of texts introduced by Yuri Lotman (1988, as cited in Wertsch 1991, pp. 73–74). Different classes of communicative approaches are defined in terms of whether the classroom discourse is authoritative or dialogic in nature and whether it is interactive or noninteractive (Mortimer and Scott 2003, p. 33). Dialogic discourses are open to different points of view. At different points in a sequence of science lessons, dialogic talk inevitably takes on a different character. Thus, at the start of a lesson sequence, the science teacher might elicit students' everyday views about a particular phenomenon. Later on, the teacher might encourage students to discuss how to apply a newly learned scientific idea in a novel context. In both cases, we can see the students agreeing on some points and disagreeing on others, but working together to understand any points of difference as they develop their explanation. It is possible to see, thus, an ongoing, dialogic interanimation of ideas.

In dialogic discourse, there is always an attempt to acknowledge the views of others, and through dialogic discourse the teacher attends to the students' points of view as well as to the school science view. By way of contrast, authoritative discourse does not allow the bringing together and exploration of ideas. Here the teacher focuses on the school science point of view. If ideas or questions that do not contribute to the development of the scientific story are raised by students, they are likely to be reshaped or ignored by the teacher. Alternatively, if a student's utterance is perceived by the teacher as being helpful to the development of the scientific story, it is likely to be seized upon and used. More than one voice may be heard in authoritative discourse, through the contributions of different students, but there is no exploration of different perspectives, and no explicit interanimation of ideas, since the students' contributions are not taken into account by the teacher unless they are consistent with the developing school science account.

A sequence of talk can be dialogic or authoritative in nature, independently of whether it is uttered individually or between people. What makes talk functionally dialogic is the fact that different ideas are acknowledged, rather than whether it is produced by a group of people or by a solitary individual. This point leads us to a second dimension in the communicative approach: that talk can be interactive, in the sense of allowing for changes of speech turns between people, or noninteractive, in the sense that only one person speaks, with no changes of turns.

Combining the two dimensions, four classes of communicative approaches can be identified:

1. *Interactive/dialogic*: Teacher and students consider a range of ideas. If the level of interanimation is high, they pose genuine questions as they explore and work on different points of view. If the level of interanimation is low, different ideas are simply made available.
2. *Noninteractive/dialogic*: Teacher revisits and summarizes different points of view, either simply listing them (low interanimation) or exploring similarities and differences (high interanimation).
3. *Interactive/authoritative*: Teacher focuses on one specific point of view and leads students through a question and answer routine with the aim of establishing and consolidating that point of view.
4. *Noninteractive/authoritative*: Teacher presents a specific point of view.

We will analyze two episodes to show how we work with the conceptual profile in the analysis of classroom discourse. These two episodes are from a sequence of science lessons to introduce some basic concepts of thermal physics and their analysis will use insights from a conceptual profile of heat (Amaral and Mortimer 2001). The teaching sequence content was organized around the topic of the thermal regulation of living beings. It included the study of heat, temperature, thermal equilibrium, and the balance of energy in organisms. The students in the target class had been introduced previously to the kinetic particle model of matter through an approach based on the interpretation of phenomena such as gaseous diffusion and changes in the physical states of matter. The lessons involved a combination of work carried out in small groups followed by whole-class discussions led by the teacher. In the small group work the students performed experiments and discussed their observations and findings. The teacher introduced each experiment with a preliminary presentation, in order to contextualize the problem and locate it within the developing teaching and learning story. In the subsequent whole class discussion, the teacher and students talked through the ideas and explanations that the students had proposed.

We will neither use all the zones of the conceptual profile of heat nor discuss how we arrived at them. We will simply consider two zones. The first one is the commonsense view that heat is proportional to temperature and is the opposite of another form of heat, cold. The second one is the scientific view of heat or heating as a process of energy transfer between systems or bodies, in which heat is proportional to differences between temperatures. Even though it may seem that we are simply contrasting a commonsense view with a scientific understanding, this is just a consequence of our choices in this particular argument. The conceptual profile of heat includes more than these two zones, as interested readers can verify in the original source (Amaral and Mortimer 2001).

The first episode took place during the first lesson of the teaching sequence. An initial activity involved students immersing one hand in cold water and the other in warm water before plunging them both into a tank of water at room temperature. The purpose of the activity was to show the limitations of the senses in monitoring temperature. During the group work the teacher noticed that students were talking about what was happening in several different ways. In the subsequent whole-class discussion the teacher encouraged the students to explain what they meant by heat and temperature during the activity.

In presenting the episodes, we decided to leave out technical marks and add punctuation to the original transcripts in the cases of pauses and interrogative intonations. We have also left out some turns of speech that are not relevant here, since they concerned issues of classroom organization and maintenance of discipline. The most delicate step in the reconstruction of classroom interactions was the translation of the Brazilian Portuguese transcripts into English.

1 Teacher: So, how do you explain it? What happens when we feel hot and cold?
2 Student 2: Maybe the temperature of the water passes to your hand when you put it in the water.
3 Teacher: What passes to your hand?
4 Student 2: The temperature.
5 Teacher: The temperature? Do you agree with that?
6 Student 5: There was a heat change.
7 Teacher: Heat change. What's that? Can you explain please?
8 Student 3: There was a kind of diffusion. The temperature of the water passes to your hand and from your hand to the water.
9 Student 6: One swops heat with the other Miss.
10 Student?: I think that it's a change of temperature.
11 Student 6: The heat warms the cold water until a point at which the temperature will transfer neither cold nor hot.

Here, Student 2 (turn 2) uses the idea of temperature in a way which is closer to the school scientific concept of heat. Students 5 and 6, in turn, refer to a heat change. In turn 11, Student 6 refers to some kind of equilibrium being achieved and in his explanation temperature is something that is able to transfer either heat or cold (probably both). In this way, a range of ideas are presented for consideration. The teacher does not evaluate or correct them, but simply asks for further clarification and prompts others to position themselves in the debate.

12 Teacher: I don't understand what you're saying. I want to know what changes between the water and the hand. . . temperature or heat?
13 Students: Temperature.
14 Student ?: It's heat, a heat change.
15 Teacher: Well, you must justify your ideas.
16 Student ?: It's because the temperature is made by heat.
17 Teacher: Hmm. . . .

Some confusion now arises in the class as one of the students, Student 4, provides a long description of the activity and other students conclude that the hand absorbs heat from the water. We do not present this part of the talk, which consists of 11 turns. The teacher, after Student 4's intervention, asks whether anybody thinks differently.

29 Student 1: I think there is a heat change because our body is always around the same constant temperature.
30 Teacher: Hmm. . . .
31 Student 1: So, if you put your hand in a bowl of warm water your temperature remains more or less the same, it doesn't change. There is a change of heat. Heat relates to what you feel, so there is a heat change and not a change of temperature.
32 Student 7: That's it. And heat can be cold or hot. It can be a cold or hot heat.
33 Teacher: Do you agree with that? Movement of cold heat and hot heat?
34 Student ?: No.
35 Student ?: Temperature is only a measure.
36 Teacher: But she is saying that. Please Student 7, explain again, because when you were saying hot and cold heat I saw someone looking surprised.
37 Student 7: I think that heat, when we talk about heat it does not mean just a hot heat, it can be cold, cold heat. For instance, in cold water we have cold heat and we felt it cold.

Throughout this episode, the teacher adopts a neutral stance, not offering evaluative comments. She prompts the students to present their ideas and asks for elaboration and justification of points of view. She also helps the students to recognize the existence of different possible interpretations of the phenomenon. For example, in turn 36, the teacher gives special attention to Student 7's explanation, which is based on the existence of two kinds of heat, corresponding to one of the zones in the conceptual profile, namely the commonsense zone. Although Student 7's explanation is not fully explored at this point, the teacher returns to it later (as we shall see in the next episode). In this way, an interactive/dialogic communicative approach is developed by the teacher and the two kinds of heat ideas are foregrounded as a theme to be further discussed.

The next episode took place in the next lesson of the sequence. It shows an example of the use of the conceptual profile of heat to build a turning point in the discourse, in which the dialog played out through the first episode changes to an authoritative discourse without giving up the commonsense zone. In the lesson, the teacher had organized a small-group activity to address explicitly the idea, from the first lesson, that there are two kinds of heat. The activity entitled, 'Can cold be hot?' involved preparing a system (ice chips with salt) that is colder than melting ice and observing what happens to the reading of a thermometer when it is moved from a beaker containing ice and salt to one with melting ice. The reading of the thermometer actually goes up as it is placed in the melting ice. The episode starts at the end of the activity, with a whole-class review of the question that had arisen in the previous discussions:

Teacher: Now let's return to our question. Last week some groups were talking about there being two kinds of heat. . . hot and cold heat. In fact, this is not a new idea. In the history of science it's been around for a long time. Also, we often think about heat in terms of our sense of touch and we have distinct senses of hot and cold. So, we naturally tend to accept that there are two opposite and separate things – hot heat, which warm objects have, and cold heat, which cool objects have. But, we have to examine these ideas to see whether they can help us understand the notion of heat or not. So, there are two things. The first relates to what we call cold, or the cold. There is nothing which is absolutely cold, isn't there? For example, melting ice. . . we think it is really cold, but is it compared to ice plus salt? Is it cold?

Student?: No.

Teacher: No, it's warm. It's a source of heat. If you put both in contact, pure melting ice will pass heat to the ice with salt. What is cold? I can say that it is less hot and the opposite is also true, hot is less cold. Cold and hot are relative ideas, aren't they? It's a matter of comparing things. So, does it help to think about two kinds of heat, one associated with hot objects and the other with cold?

Here the teacher returns to the idea, introduced by Student 7 in the first episode, that there are two kinds of heat, both hot and cold. The teacher starts by referring to the historical origins of this idea and makes a link to the students' commonsense ideas. She then refers to the findings of the earlier practical activity and challenges the two kinds of heat view, giving support to the scientific perspective that cold and hot are relative ideas. Hence, initially, the teacher adopts a noninteractive/dialogic communicative approach, comparing and contrasting points of view from the first lesson. However, once the teacher acknowledged and positively appraised the two kinds of heat point of view (by making a link to historical perspectives and to the physical sensations of hot and cold), she introduces the scientific perspective. There is a clear movement toward the authoritative pole of the dialogic/authoritative dimension. This episode thus constitutes a turning point (Scott et al. 2006) in the flow of discourse of this lesson sequence, as the teacher brings together everyday and scientific views and makes an authoritative case for the scientific view that there are not two kinds of heat. The teacher has developed the case by engaging the students in an activity that offers a vivid example of a cold object (melting ice) actually being warmer than another object (ice plus salt). The noninteractive/authoritative argument that the teacher develops is based on the shared outcomes of this activity. At this point, she is doing all the talking and it would certainly be wrong to assume that all students have taken on the scientific view. Nevertheless, in subsequent small group and whole-class discussions, there were many opportunities for students to articulate their developing ideas about heat, and the two kinds of heat idea was not raised again, either by the teacher or the students.

The sequence of communicative approaches in these two episodes enabled the dialog between old and new zones of a conceptual profile, and we believe this is of fundamental importance in supporting meaning making by students. Thus, the students have the opportunity to position the authoritative discourse of the disciplinary knowledge in relation to their everyday views and, in so doing, we believe that they are better placed to appropriate this discourse and to make it their own. In simple terms, the students are better placed to see how the different ideas fit together.

These episodes provide an example of how conceptual profiles can both inform discourse analysis of classrooms and the planning of activities to deal with science teaching and learning. Conceptual profiles have already been built for three basic quite general definitions – matter (Mortimer 2000), energy (Amaral and Mortimer 2004), and life (Coutinho et al. 2007a, b), and the related concepts of particulate models of matter, atom, and molecule (Mortimer 2000; Mortimer and Amaral 1999); heat, entropy, and spontaneity of physical and chemical processes (Amaral and Mortimer 2004); life and living beings (Coutinho et al. 2007a, b); and adaptation (Sepulveda et al. 2007). Several studies about meaning making in science classrooms are being carried out using conceptual profiles as tools for investigating the cognitive dimension of discourse. Other studies have been employing conceptual profiles as grounds for devising teaching sequences at different educational levels.

Concluding Remarks

In this chapter, we have addressed the issue of heterogeneity in talking and thinking in science classrooms, drawing upon several related theoretical perspectives and culminating in the conceptual profile approach. We see the kind of discussion presented here as being important not only in terms of the theoretical analysis, but also in relation to the potential for developing greater clarity in understanding the interactions and learning in real classrooms and for planning more effective instruction.

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Chapter 18
Quality of Instruction in Science Education

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International large-scale assessments revealed remarkable differences in students' science achievements between countries. In the 1995 iteration of the Third International Mathematics and Science Study (TIMSS), students' achievements were less than expected for countries as developed as the United States, Germany, and France (Beaton et al. 1997). These results were confirmed by the Programme for International Student Assessment (PISA) studies (e.g., Organisation for Economic and Cultural Development (OECD 2001). In consequence, a discussion arose in major western countries about the quality of education in general and the quality of instruction in particular.

Attempts to identify and describe quality of instruction and its components were undertaken already in the 1960s. These attempts were followed by extensive research programs on teacher effectiveness in the late 1960s and 1970s. Systemization of results from research on teacher effectiveness on the basis of quality of instruction models led to another boom in research in the late 1970s and 1980s – mainly comprising metaanalyses. Since these efforts were not satisfying with respect to explaining instructional outcomes in general, with the TIMSS study, a new attempt was

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made to investigate instruction and to relate instructional characteristics to students' achievement. This was mainly because video analysis of lessons became technically possible. Video analyses allowed to record classrooms and analyze instruction in an extensive and thorough manner in multiple iterations.

This chapter presents a review of research on quality of instruction in science education including different general theoretical frameworks. Firstly, early attempts in modeling quality of instruction will be described. Based on these models, the extensive amount of studies on teacher effectiveness research will be summarized by the help of metaanalyses and research reviews. Furthermore, recent video-based studies and their results will be described. From the discussed works, finally, dimensions of quality of science instruction will be derived.

Models of School Learning

A first consideration of instructional quality can be found in John Carroll's (1963) model of school learning. In this model, students' degree of learning is described as the ratio of the time a student actually spends on learning and the time a student needs to spend on something in order to learn it. Carroll (1963) defined the time actually spent for learning as a function of opportunity and perseverance, and the time needed as a function of aptitude, ability to understand instruction, and quality of instruction. As to quality of instruction, he suggested a constituting set of characteristics – namely clarity of the learning goals, adequate presentation of the learning material as well as a planned series of learning steps (cf. Carroll 1989).

In the light of research on learning processes by Robert Gagné (1965), Benjamin Bloom (1976) takes a shift away from the relevance of time as such and towards the learning process itself. While he emphasizes the importance of students' prerequisites, in particular their cognitive abilities, for the learning process, he also identifies a set of characteristics influencing the learning process: According to him, cues and feedback have a moderate influence on achievement gains, while reinforcement and participation have a small influence only. However, the overall influence of quality of instruction as well as of students' affective characteristics on student achievement is considered to be only moderate while students' cognitive abilities are considered to have the highest influence (cf. Bloom 1976).

Two other works, by Robert Slavin (1987) and Bert Creemers (1994), set off to systematize existing results from research on instruction on the grounds of Carroll's (1963) model. Creemers (1994) described quality of instruction as the quality of curriculum and its implementation in instruction, grouping procedures as well as characteristics of teachers' behavior. Essential characteristics of teacher behavior are the structuring of content, clarity of presentation, questioning, immediate exercise after presentation, evaluating whether goals are achieved, and corrective instruction (van der Werf et al. 2000). Slavin (1987) reduced Carroll's (1963) model to four elements: quality of instruction, learning time, appropriate levels of instruction, and incentive. Whereas all four elements were considered equally important for effective

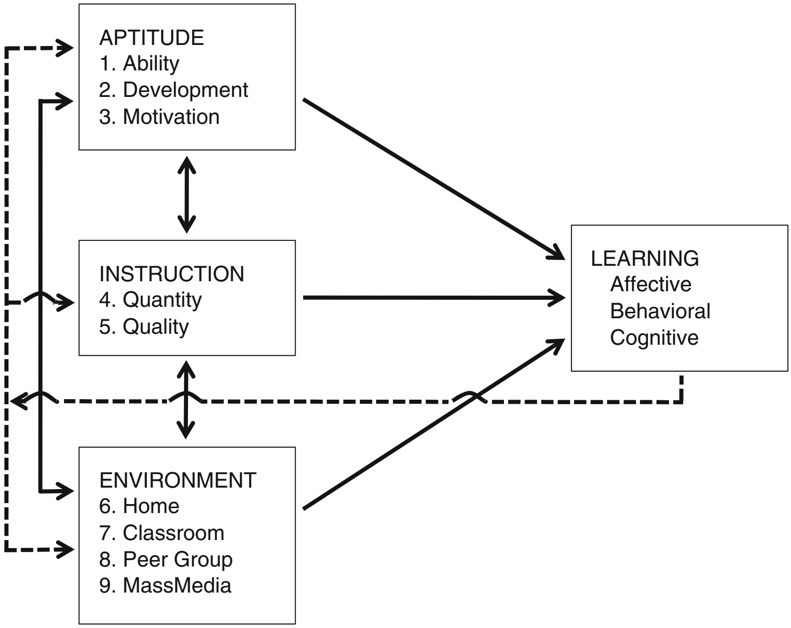

Fig. 18.1 Walberg's (1981) model of educational productivity. Adapted from Fraser et al. (1987, p. 157)

instruction, none of them can be compensated by one of the others. As to quality of instruction, Slavin (1987) compiles a list of characteristics similar to Creemers' (1994) list of teaching or teachers' characteristics, respectively (cf. Gruehn 2000).

Another model that has evolved from Carroll's (1963) model of school learning is the model of educational productivity proposed by Herbert Walberg (1981). Walberg (1981) presented a first systematization of research on modeling school learning and the products of school learning (Gruehn 2000). A major new feature in Walberg's (1981) model was the provision of the learning environment and its influence on students' learning time. Altogether, Walberg (1981) identifies at first seven and in later works nine factors that influence affective, behavioral and cognitive learning: ability or prior achievement, age and development, motivation or self-concept, quantity of instruction or time engaged in learning, quality of instruction, home environment, classroom environment, peer group environment, and the mass media (Fig. 18.1; cf. Fraser et al. 1987). Quality of instruction in this model is related to the degree of direct instruction (Rosenshine 1979).

Summarizing, it has to be maintained that within the above models instruction is described as a function of student individual characteristics, instructional characteristics, and characteristics of the learning environment providing information on the quality of the learning process and in consequence of instructional outcomes. Quality of instruction is considered a set of instructional characteristics, as for example, clarity and structure or teacher–student interactions. Outcomes can be affective, behavioral or cognitive, where the focus is mostly on the latter, that is, students' achievement. Walberg's (1981) model takes an exceptional position in scope of the discussed models. It is a synthesis of all proceeding models at least with respect to the first five factors it embraces, while it accounts for the learning environment through inclusion of the remaining four factors (Gruehn 2000). Finally, it describes quality of instruction on the basis of empirical research on teaching effectiveness. The models discussed so far are proposed for instruction and learning in general. Specific characteristics of individuals and environments are taken into account but domain specifics, that is, subject matter or subject specific learning processes, remain unconsidered.

Teacher Effectiveness Research

Early research on teacher effectiveness followed two different research approaches: The teaching process paradigm on the one hand and the criterion of effectiveness paradigm on the other (Gage 1972). Within the teaching process paradigm, what characterizes a good teacher was defined based on experts' experience or observations of classroom learning (Rosenshine and Furst 1971). The criterion of effectiveness approach on the other hand drew on outcome criteria, for example, student achievement, for identifying characteristics of effective teaching (Shavelson and Dempsey-Atwood 1976). A first major review of research on the latter is given by Barak Rosenshine and Norma Furst (1971). They derive a set of 11 different variables, amongst which Clarity, Variability, Enthusiasm, Task-oriented and/or Businesslike Behaviors, and Students' Opportunity to Learn Criterion Material are considered as particularly important. However, Rosenshine and Furst (1971) state a lack of substantial research on teachers' characteristics relating to higher student achievement and demand further research in this field to back up the relevance of the characteristics compiled by them.

In another attempt to summarize the general factors that influence classroom learning, Michael Dunkin and Bruce Biddle (1974) developed the so-called "process-product model" of classroom learning. The model embraces four classes of variables: teacher characteristics (e.g., personality), context variables (e.g., classroom environment), process variables (e.g., learning activities), and product variables (e.g., student achievement) (cf. Shuell 1996).

In the decade following Dunkin and Biddle's (1974) work, the research base has been considerably broadened. The 1970s and 1980s provided a substantial amount of correlational and experimental studies that documented causal relationships between teacher behaviors and student achievement. In reference to the model suggested by Dunkin and Biddle (1974), this research is termed *process-product research*. Studies provided evidence that classroom management influences student achievement (Good 1979). Other studies indicated that managing classrooms effectively begins on the first day of school with a systematic approach, advance preparation, and planning (Evertson 1985). With reference to the core idea of Carroll's (1963) model of school teaching and learning, much research focused on the investigation of time-on-task. Results documented the importance of time-on-task, pointing out that students must become actively engaged in learning during instruction time (Anderson 1981).

In a review of several metaanalyses, Ronald Anderson (1983) summarizes the results of research on teacher effectiveness specific to science education. His analysis confirms the superiority of an inquiry approach in, for example, curricula or teaching techniques, although effect sizes vary heavily between metaanalyses. Additionally, effects with respect to the teaching of process skills were found. Interestingly, effects were noticeably larger in studies testing students for specific techniques but small in those testing for scientific methods in general.

An all-embracing review of process-product research was written by Jere Brophy and Thomas Good (1986) identifying two dimensions of characteristics: characteristics related to quantity and pacing of instruction on the one hand and qualitative characteristics on the other. As to quantitative characteristics, they find the amount of opportunities to learn and the content covered, role definition/expectations/time allocation, classroom management/student engaged time, consistent success/academic learning time, and active teaching to have a positive impact on instructional outcomes. With respect to qualitative characteristics, giving information (including structuring, redundancy/sequencing, clarity, enthusiasm and pacing/waiting time), questioning the students (including difficulty level of questions, cognitive level of questions, clarity of questions, selecting the respondent, waiting for the student to respond), as well as reacting to students' responses (including, for example, reactions to correct and incorrect responses), handling seatwork, and homework are identified (cf. Brophy 1986). These results, although formulated in a different way, strongly support the characteristics of effective teaching found by Rosenshine and Furst (1971). The aspect of clarity can be found in both reviews; variability in Rosenshine and Furst's (1971) review relates to the cognitive level in discourse and, thus, is included in questioning students – as is enthusiasm. Task/business-like behaviors refer to characteristics subsumed under quantitative characteristics. In addition, Brophy and Good (1986) emphasize the importance of structuredness of content as suggested by David Ausubel (1968), Jerome Bruner (1966) and other cognitive structuralists.

Particularly interesting is the work of Barry Fraser et al. (1987) as it presents a synthesis of educational research. Based on Walberg's (1981) model of educational productivity, research reviews of the 1970s were analyzed, from which productive factors of learning were obtained. In addition, quantitative syntheses or metaanalyses of studies of these factors were accomplished. Fraser et al. (1987) found that three groups of aptitudinal, instructional, and environmental factors have influences on instructional outcomes, that is, cognitive, affective, and behavioral learning. The strongest effects were found for variables of students' aptitude, wherein intelligence was found to be the strongest factor. As to quality of instruction, Fraser et al. (1987) found a mean effect size for time and strong effects for reinforcement, instructional cues, engagement, and feedback. The works of Fraser et al. (1987) are remarkable in another way as well, as the authors derive a model to describe contextual and transactional influences on science outcomes, which after the work of Anderson (1983) is a particular attempt in describing a model of instructional quality specifically for science education. Fraser et al. (1987) found the strongest factor of quality of instruction to be the time between a teachers' question and students' answers, followed by focusing (e.g., organizers), students' hands-on activities, use of teacher questioning or – in line with Anderson (1983) – inquiry learning. The overall mean effect size of the factors established was one-third of a standard deviation (Fraser et al. 1987).

A further probe of the model of educational productivity is accomplished by Herbert Walberg et al. (1981) using data from the National Assessment of Educational Progress (NAEP) program. By regression analysis, the factors Socioeconomic Status, Motivation, Quality of Instruction (measured by a questionnaire on students' perception of the degree of direct, didactic instruction), Class (social psychological environment), and Home conditions were each found to be significant. While other factors such as race and gender where controlled, "Under a stringent probe, however, the Class social-*psychological* environment appears as the only unequivocal cause of science learning in the data" (Walberg et al. 1981, p. 233). These results are confirmed by Margaret Wang et al. (1990), who find classroom management and climate together with student-teacher interactions to form an important set of instructional characteristics related to effective instruction.

Altogether, from research on teacher effectiveness, five dimensions of variables may be identified: clarity, structuredness, cognitive activation, pacing, and classroom management. Clarity refers to the clarity of learning goals, the presented content and so on, and structuredness refers to a systematic approach in the design of instruction. Cognitive activation embraces all variables relevant to activate students cognitively, for example, the cognitive level of tasks as well as variables related to students' engagement. Pacing is related to the adequate sequencing of tasks, in which adequateness means adequate with respect to students' abilities rather than an adequate content structure. Finally, classroom management refers to an adequate learning climate that allows for an effective learning. An important characteristic, which is not part of the above dimensions, would be teacher enthusiasm. This characteristic is not considered part of the actual instruction but rather is part of a whole set of characteristics related to a teachers' traits. These characteristics certainly will have to be included in a model of quality of instruction as they influence design and implementation of instruction (Wayne and Youngs 2003).

Video Studies of Instruction

Quality of instruction research received a major revival with the so called TIMSS Video Study (Stigler et al. 1999). As video recording and analysis became technically possible, this offered a new approach to the analysis of instruction. Video analysis preserves classroom activity so it can be viewed several times allowing for a detailed examination of the complex actions taking place in classrooms. In scope of the TIMS Video Study, this method was used to analyze mathematics lessons from Germany, Japan, and the United States to identify instructional characteristics relevant for differences observed in students' achievements in the TIMS study (Beaton et al. 1997). Analysis covered the content of the lessons, the teachers' aims as well as teachers' and students' manuals, verbal activities, and the material used. The analysis revealed the existence of specific patterns of instruction in Germany, the United States, and Japan – so-called lesson scripts (Stigler and Hiebert 1997). While instruction in Japan is characterized by a rather constructivist approach, instruction in Germany was identified as narrowly guided and result-oriented. Lesson scripts were considered to be highly culture specific (Stigler and Hiebert 1997). Despite that, no explanation for performance differences between the participating countries could be found (Stigler et al. 1999).

Thus, an aim of a further video study in scope of the 1999 iteration of TIMSS was to investigate whether high achieving countries share a common method of teaching (Hiebert et al. 2003). This time, science instruction was also video recorded and analyzed. In mathematics, lessons were videotaped in Australia, the Czech Republic, Hong Kong, the Netherlands, Switzerland, and the United States. Additionally, Japanese lessons from the earlier study were reanalyzed. Results of the preceding video study could be confirmed in general. Again, lesson structures similar to the ones found in the scope of the TIMSS Video Study could be observed. Differences appear, however, when investigating the characteristics of tasks. While in most countries the majority of problems presented during instruction were of low complexity, in Japan about 40% of the problems used were of high complexity. Also, in Japan in over 40% of the tasks, a previous task's solution was used to solve the given task, whereas at least 65% of the tasks in other countries were repetitive, that is, a task was the same or mostly the same as the preceding one (Hiebert et al. 2003). Yet, as the majority of Japanese mathematics lessons dealt with geometry and was videotaped 4 years earlier, the interpretation is not very powerful.

Results of the science part of the study were published in 2006 by Kathleen Roth et al. (2006). Based on an extensive literature review of research on teacher effectiveness, criteria of instructional quality were compiled and categorized in three classes: science content, teacher actions, and student actions embedded in school culture. Analyzing science instruction in Australia, the Czech Republic, Japan, The Netherlands, and United States on the grounds of this framework, Roth et al. (2006) found that high achieving countries shared two common characteristics: high content standards and a content-focused instructional approach. However, these high content standards were embodied by different characteristics per country, as, for example, the density and challenge of content ideas or students being held responsible for their own independent learning.

In summary, while the TIMSS video studies provided an extensive description of mathematics and science instruction, they failed in relating instructional characteristics to student achievements. This lack of reliable findings on the influence of country-specific patterns of instruction on students' performance led to a series of research projects investigating instruction by means of video analysis.

In an effort to shed more light on the complex matter of science instruction, a video study was undertaken by the Institut für die Pädagogik der Naturwissenschaften (IPN) in Kiel, Germany. The scope of this video study of physics instruction was to investigate teaching and learning processes (Seidel et al. 2007). Based on the results of research on teacher and teaching effectiveness, taking the "complex mediating process from instructional activities to student learning" (Seidel et al. 2005, p. 552) into account, a theoretical framework was used as a basis of a multitrait multimethod approach to examine physics instruction. Classroom activity patterns were investigated, aspects of instructional quality were surveyed, and finally these findings were related to student reports on cognitive learning processes, quality of learning motivation, and perception of supportive learning conditions (Seidel et al. 2005). Results on physics instruction were in line with the findings from the TIMS video study on mathematics instruction: German physics instruction is characterized by a narrowly focused questioning–developing teaching style. This was confirmed by Thomas Reyer (2004) who found that physics instruction is mainly characterized by a teacher-centered instruction using demonstration experiments and seldomly by student-centered instruction using experimental group work. However, Tina Seidel et al. (2007) could not find an influence of either approach on student learning. A more in-depth analysis, though, provided empirical evidence for several assumptions on quality of instruction: Goal clarity and coherence have a positive influence on students' perceptions of supportive learning conditions. Interactions in class work were found to be related to motivational affective development (cf. Seidel et al. 2005). Further, students perceived themselves as being more self-determined and motivated in classrooms with high quality classroom discourse (Seidel et al. 2003), that is, with high cognitive activation. Analysis of the use of experiments pointed toward a lack of support and self-contained learning during experimental phases (Tesch and Duit 2004).

Similar results could be found in a Swiss-German cooperation project "Instructional Quality and Mathematical Understanding in Different Cultures" (Rakoczy et al. 2007). Based on an opportunity-to-learn model of instructional quality (Fig. 18.2), a three-lesson unit was videotaped in 20 German and 20 Swiss classes. Analysis was based on three dimensions of teaching quality: classroom management, cognitive activation, and student-centered orientation (Lipowsky et al. 2005) as well as structure of the content presented (Rakoczy et al. 2007). Results provided evidence that student achievement is higher in classes with high cognitive activation. Also, classroom discourse was found to have an influence on student achievement. Together, both characteristics explained 9% of students' achievement (Lipowsky et al. 2005). Additionally, a structured presentation of content was found to have a particular influence on student achievement (Rakoczy et al. 2007).

In another approach, the data were analyzed with respect to instructional patterns (Hugener et al. 2007). Altogether, three patterns with respect on how the solution to problems posed during instruction is handled could be identified: a presenting pattern, a development pattern, and a discovery pattern. In line with the results of the TIMS Video Study described above, the discovery pattern was related to the highest

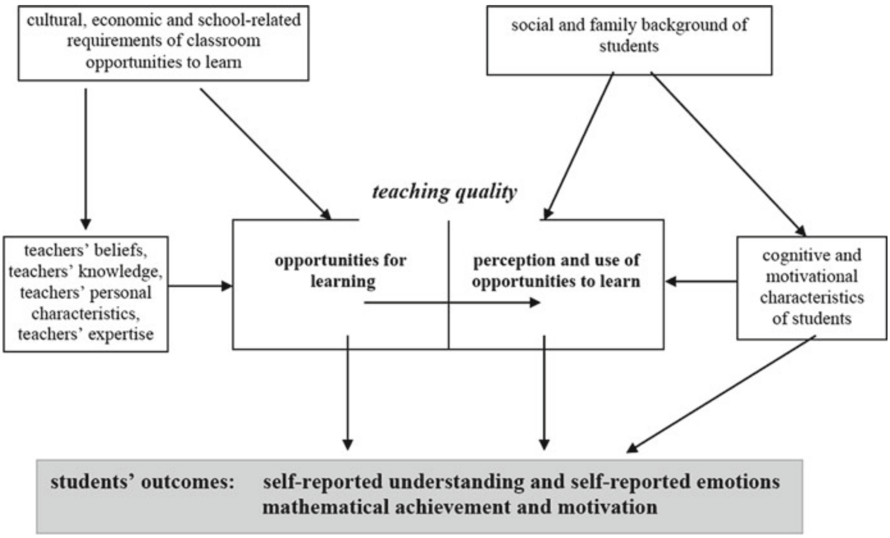

Fig. 18.2 Model of instructional quality. Taken from Lipowsky et al. (2005)

cognitive activation although again no influence on student achievement could be observed. This allows for the conclusion that while instruction might look the same on a surface level of instruction, instructional characteristics influencing students' achievement might be located on a deeper level.

Apart from the presented video studies investigating instruction as a whole, a lot of studies have taken into focus different aspects of instruction on a descriptive base or correlational base with respect to student outcome. Eduardo Mortimer and Phil Scott (2003), for example, focus on a description of classroom or student–teacher interaction, respectively, particularly on dialog structures in the classroom. Others investigate the teachers' role in supporting learning in different teaching-learning environments (e.g., Viiri and Saari 2004). However, it is too early, yet, to draw conclusions as more studies will be needed to confirm the findings and allow for metaanalyses to create a larger picture of how these characteristics relate to each other and how they contribute to quality of instruction in general.

In summary, earlier video studies of instruction were not able to establish a relation between characteristics of instruction and students' achievement, whereas later ones were more successful as they set a stronger focus on deep-level characteristics of instruction and were based on more elaborate models of instructional quality. Results of the later investigations show that clarity, classroom management, cognitive activation, and structuredness have an impact on outcome criteria. This confirms the dimensions that could be identified from teacher effectiveness research. And while these dimensions are not specific to science education, their relevance to science education can be concluded from the described studies.

Summary and Outlook

Early models of school learning describe quality of instruction as a set of instructional characteristics influencing the learning process and thus mediating the influence of students' prerequisites on students' outcomes. In later models, the extensive amount of research on teacher effectiveness is systematized leading to five dimensions of instructional quality: clarity, structuredness, cognitive activation, pacing, and classroom management. The rapidly developing video recording technology allowed for a large-scale use of video equipment to record and to analyze lessons. And while early video studies struggled to identify instructional characteristics, later ones were – on the basis of theoretically founded models of instructional quality – able to provide evidence on the importance of the above dimensions. However, more research is needed especially on science-specific aspects of instructional quality. That is, on science-specific operationalizations and the interplay of the above dimension as well as the relevance of science-specific instructional characteristics, that is, the use of experiments.

Moreover, further research should take characteristics of students, teachers, and the classroom environment and their influence on the above dimensions of instructional quality into account. This is especially important as there is evidence that a mere change of instructional patterns does not influence student outcome and that quality of instruction is to be sought on the deep level of instruction. This again means that teacher training programs seeking to improve quality of instruction have to focus on teachers' professional knowledge to efficiently change the way instruction is designed and implemented.

Finally, as it seems that aptitudes are powerful correlates of learning; they deserve inclusion in theories of educational productivity.

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Chapter 19
Personal Epistemology and Science Learning: A Review on Empirical Studies

Fang-Ying Yang and Chin-Chung Tsai

Personal epistemology is usually perceived by psychologists and educators in psychology research as beliefs about the nature of knowledge and knowing. The pioneer study about personal epistemology is John Perry's (1970) study on intellectual development. Based on 20 years of longitudinal studies, Perry proposed the Perry Scheme that shows the developmental stages of personal epistemology starting from dualism, to multiplicity, and relativism. A critical perspective of the Perry Scheme is that the transformation of personal epistemology progresses with years of higher education. The developmental perspective about personal epistemology is supported by many scholars such as Patricia King and Karen Strohm Kitchener (1994) and Deanna Kuhn (1991), even though they studied different cognitive behaviors and suggested different developmental models.

In addition to the developmental stand, some researchers (e.g., Marlene Schommer-Aikins 2002) claimed independence among epistemological belief dimensions, whereas others (e.g., Barbara Hofer 2001) argued the systematic or ecological interrelation among dimensions of personal epistemology. As a matter of fact, studies about personal epistemology have been conducted in various branches of psychology and education with different labels such as epistemological beliefs, reflective judgment, epistemological reflection, epistemological theories, and so forth. Although there is no united definition for personal epistemology, a common interest among epistemological researchers is evident in individuals' thinking and beliefs about knowledge and knowing (see the review by Jean E. Burr and Barbara K. Hofer 2002).

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According to Barbara Hofer and Paul Pintrich (1997), personal epistemology consists of four well-recognized dimensions, including certainty of knowledge, simplicity of knowledge, source of knowledge, and justification for knowing. From a developmental point of view, beliefs about the nature of knowledge and knowing are articulated by educational experiences (Hofer and Pintrich 1997; Perry, 1970). Accordingly, an individual's view about the nature of learning should also be an indicator of a person's epistemological theory. In view of that, Schommer-Aikins (1990, 2002) proposes that beliefs about learning are also a significant constituent of personal epistemology. Although Schommer's model of an epistemological system has received criticisms (Hofer and Pintrich 1997), her work initiates an important line of research linking epistemological beliefs to issues about classroom learning.

Psychological studies have shown that personal epistemological beliefs mediate cognitive activities relevant to learning and reasoning. For example, King and Kitchener (1994) verify the developmental association between personal epistemology and reflective reasoning; Kuhn (1999) proposes a similar link between personal epistemology and critical thinking; Perry (1970) and Hofer (2001) point out that education affects belief and epistemological development; and Goayin Qian and Donna Alvermann (2000), and Schommer-Aikin (1990, 1993) further demonstrate the significant contributions of personal epistemology to school performance. In addition, Chin-Chung Tsai (2000a) and Fang-Ying Yang (2005) with Taiwanese samples also confirm that personal epistemology is significantly correlated with learning approaches and scientific reasoning in informal contexts.

Although the role of personal epistemology in human cognition is well recognized, there remain many unsolved issues regarding operational definitions for the construct, dimensions of personal epistemology, domain specificity, assessments, developmental trajectory, and so forth. Many review and empirical papers have thoroughly discussed these issues. For instance, Hofer (2000, 2001) analyzed the dimensions of personal epistemology and discussed the educational implications of relevant research; Burr and Hofer (2002) examined thoroughly the conceptions of personal epistemology; and Orpha Duell and Marlene Schommer-Aikins (2001) reviewed assessment of personal epistemology. More recently, Krista Muis, Lisa Bendixen, and Florian Haerle (2006) explored the issue of domain specificity. Thus, these issues are not the foci of this chapter. In this chapter, we intend to discuss the role of personal epistemology with particular attention to science learning.

Personal Epistemology and Science Learning

Based on Benjamin Bloom's taxonomy (1956), education activities can be categorized into cognitive (knowledge), psychomotor (skills or processes) and affective (beliefs, values, and attitudes about science) domains. Accordingly, in addition to factual knowledge and process skills and/or problem solving strategies, it has been widely agreed among science educators that students need to be taught about the nature of science as they are expected to appreciate the differences between science and other disciplines. In the relevant literature that deals with factors affecting science learning, considerable attention has been placed on examining the effects of prior knowledge. For example, exploring misconceptions and/or alternative frameworks is a popular research topic regarding concept learning (Carmichael et al. 1990; Vosniadou and Brewer 1992). As far as the learning of process skills is concerned, the practice of inquiry skills has been found to be influenced by domain-specific knowledge (e.g., Lazonder et al. 2008; Trumbull et al. 2005). As for learning about the nature of science, students' prior understanding about the structure of theory and evidence (data) and subject-matter knowledge are the central topics of discussion (e.g., Lederman 1992; Sadler and Zeidler 2004). In addition to prior knowledge, affective factors such as attitudes, interest, expectations, and values have also been found to play a significant role in mediating science learning (e.g., Pintrich 1999; Spinath and Stiensmeier-Pelster 2003).

As mentioned previously, psychological studies about personal epistemology have gradually gained attention since the 1970s, and it has been shown that this psychological construct contributes significantly to school achievement and mediates learning (e.g., Hofer 2001; Schommer-Aikins 1993). Nevertheless, in science education research, the effects of personal epistemology have only been explored over the last decade. By this literature review, we attempt to make clear what we know and do not know about the role of personal epistemology in science learning.

In this study, 37 empirical papers that investigated the relationships between personal epistemology and science learning are reviewed. These papers are mostly selected from the Social Sciences Citation Index (SSCI) database in the ISI web of knowledge. The methods and assessment tools for detecting personal epistemology and dimensions of personal epistemology in relation to science learning are summarized in Appendix. By reviewing these studies, we try to disclose the trend of research that has been developed in the last 10 years, and reveal future research possibilities. In the following sections, we will present firstly the methods and tools used to assess personal epistemology in the context of science learning, followed by introduction of dimensions of personal epistemology scrutinized by researchers of science education. The third part of the presentation is the effects of personal epistemology on science learning. Finally, suggestions for future studies are discussed.

Assessing Personal Epistemology in the Contexts of Science Learning

Among the 37 selected papers, 22 involved high school students (grades 7–12), 10 involved university students, two studied both high-school and university students, and only four investigated elementary learners (among the four, one involved both elementary and high school subjects). As listed in Appendix, 16 selected studies used quantitative instruments, 14 employed qualitative methods, and 7 adopted mixed methods using both qualitative and quantitative tools to assess students' personal epistemological beliefs in the context of science learning. In general, quantitative studies usually employed five-point Likert-scale questionnaires that can be divided into domain-general and domain-specific types. The most popular domain-general tool is those questionnaires modified from Schommer's Epistemology Questionnaire (SEQ) developed by Schommer-Aikins (2002, 2004), which focuses on describing the nature of knowledge and learning. As shown in the Appendix, there are six papers developing modified SEQ surveys including papers such as Enman and Lupart (2000) and Lodewyk (2007). Other than the SEQ, E. Michael Nussbaum, Gale Sinatra, and Anne Poloquin (2008) used the Epistemic Beliefs Assessment (EBA) instrument developed by Deanna Kuhn, Richard Cheney, and Michael Weinstock (2000). Yang (2005) employed the Learning Environment Preference (LEP) questionnaire developed by William Moore (1989) to detect student epistemological development on the dimensions established by Perry (1970). It should be noted that when these questionnaires are used for investigations in the context of science learning, the referred knowledge domain in the questionnaires should be science.

Development or use of the domain-specific questionnaires for assessing students' personal epistemological perspectives in science was found in 11 papers. Questionnaires of this kind include the Greek Epistemological Beliefs Evaluation Instrument for Physics (GEBEP) (Stathopoulou and Vosniadou 2007), Pomeroy's (1993) questionnaire (e.g., Tsai 1998a, b), the Scientific Epistemological Views (SEV) survey (Liu and Tsai 2008; Tsai and Liu 2005), Elder's (2002) Epistemological Beliefs Questionnaire (EBQ) (Conley et al. 2004), and the Conception of Learning Science (COLS) questionnaire (Lee et al. 2008). Items in these questionnaires reflect largely the nature of knowing in science, justification criteria, social/cultural attributes, and beliefs about learning science. The contents of these questionnaires will be described more in the next section.

In addition to the quantitative studies, 14 papers adopted qualitative designs to explore personal epistemological beliefs. As shown in the Appendix, 10 papers used interviews' Chu and Treagust (2008) and Hogan (1999) were two examples. There was one study employing an open-ended questionnaire (Zeidler et al. 2000) and one using essay (Roth and Lucas 1997). Three studies made use of e-journal writing (May and Etkina 2002; Sandoval 2003; Sandoval and Reiser 2004). Some researchers have constructed written survey items that describe detailed information about lab work and the nature of theory and data (e.g., Leach et al. 2000). In addition, there are seven studies using both interview and Likert-scale questionnaires to probe students' epistemological beliefs. These seven papers are shown in the Appendix and include papers such as Hogan and Maglienti (2001) and Tsai (1998a, b). They either collected responses from limited subjects for construction of Likert-scale questionnaires or employed existing questionnaires to distinguish different types of students for in-depth interviews.

In summary, participants involved in the investigations in these selective studies were mostly high school and university students. The use of quantitative instruments to assess learners' epistemological beliefs is dominating in research about science learning. Epistemological questionnaires modified from the SEQ are the most popular domain-general tools while more and more researchers are developing domain-specific assessments. As for qualitative studies, interview and open-ended questionnaires are frequently utilized in the qualitative designs. Likert-scale questionnaires usually suffer from the unstable reliabilities of the instruments. Although qualitative analysis is recognized as the highly valid method for assessing epistemological beliefs (Hofer 2002), given the time constraints, they are limited in the number of subjects that can be involved in an analysis. Consequently, the mixed use of qualitative and quantitative methods could be a promising approach. However, the number of such studies on the record is lower than those of either qualitative or quantitative methods.

Dimensions of Personal Epistemology in the Contexts of Science Learning

From a philosophical perspective, personal epistemology concerns an individual's beliefs about the nature of knowledge and knowing. Although it is still in debate, some psychologists such as Andrew Elby (2009) and Schommer-Aikins (2004) think that the inclusion of beliefs about learning in personal epistemology is necessary because in a way learning indicates the nature of knowing and knowledge construction. In epistemological studies relevant to science learning, the above-mentioned three aspects of beliefs are constantly the foci of attention, that is, beliefs about the nature of knowledge, beliefs about the nature of knowing, and beliefs about learning. Nevertheless, because of different research objectives and research methods, different researchers use different terminologies to describe students' epistemological beliefs. Therefore in this section, the dimensions of personal epistemology proposed by researchers in the area of science education are analyzed.

As mentioned previously, among the papers analyzed in this chapter, questionnaires modified from the SEQ are popular domain-general instruments to assess personal epistemological beliefs. Basically, dimensions of personal epistemology defined by the modified SEQ surveys fall within the scope of beliefs about the nature of knowledge and learning. Significant dimensions discussed in these papers included beliefs in certain knowledge, simple knowledge, quick learning, and fixed ability (e.g., Lodewyk 2007; Rodriguez and Cano 2007). Apart from the nature of knowledge and learning, Nussbaum and colleagues (2008) who employed EBA call attention to the dimension pertaining to the judgment of knowledge.

Scholars who utilized or developed domain-specific questionnaires for assessing students' scientific epistemological beliefs tend to emphasize the nature of scientific knowledge and the construction of scientific knowledge. For example, studies that employed Pomeory's questionnaire distinguish epistemological views into empiricist and constructivist perspectives about scientific knowledge (e.g., Tsai 1999a, b) and activities in science (Tsai 2000a, b). The SEV questionnaire developed by Chin-Chun Tsai and Shiang-Yao Liu (Tsai and Liu 2005; Liu and Tsai 2008) highlights the tentative nature of scientific knowledge and social/cultural aspects of scientific communities. In addition to the structure and the stability of scientific knowledge, the GEBEP questionnaire developed by Cristina Stathopoulou and Stella Voniadou (2007) has taken into account the source and judgmental aspects of knowing. Anne Marie Conley et al. (2004) employed EBQ to assess epistemological beliefs about science, which focused on the dimensions of source, certainty, development, and justification. A study (Min-Hsien Lee et al. 2008) examined high school students' conceptions about learning science that reflect the beliefs in the goals and process of science learning, representing students' beliefs particularly toward science learning.

Those with qualitative methods display a wider range of epistemological dimensions about the nature of scientific knowledge and construction of scientific knowledge. For instance, Wolff-Michael Roth and Keith Lucas (1997) showed in their study that students displayed nine discourse resources to justify ontological, epistemological, and sociological claims. Hyun Ju Park (2007) proposes the epistemological commitments (concerning the truth of a piece of knowledge and justifications for knowledge and knowing), the metaphysical beliefs (regarding beliefs about the ultimate existence of qualities or properties of objects or phenomena), and the beliefs about knowledge, learning, and conception, as major components of conceptual ecologies. Other epistemological dimensions appearing in the collection of papers in this review were found in student discussions or discourses about issues related to the nature of scientific knowledge and knowledge construction. These dimensions included beliefs about the nature of data and explanation or conclusions (Sandoval 2003), beliefs about the goal of science, the nature of evidence, theory, and experiments/investigations (Sandoval and Morrison 2003; Zeidler et al. 2000), beliefs about changes and processes of change in science (Hogan 1999; Sandoval and Morrison 2003), and beliefs about processes of learning different science disciplines (Hye-Eun Chu and Treagust 2008; Watters and Watters 2007).

In summary, when the research about personal epistemology is placed in the context of science learning, three types of epistemological beliefs are found to be significant. One is related to beliefs about the nature of knowledge with dimensions emphasizing tentativeness, structure, and forms of scientific knowledge. Another is belief about the nature of knowing the dimensions of which include nature of scientific activities, judgmental criteria for knowledge construction, and social/cultural impacts of scientific community. The other dimension is belief about the nature of learning with respect to the goals of science learning, and processes of learning different scientific disciplines.

Effects of Personal Epistemology on Science Learning

As mentioned before, education activities include not only cognitive (knowledge) and psychomotor (skills or processes) domains but also the affective domain that entails beliefs, values, and attitudes about science. In the section, we will examine the effects of personal epistemological beliefs on science learning of different domains.

Cognitive Domain: Concept Learning

Among the selected 37 studies that examined the effects of epistemological beliefs on science learning, there are 12 papers targeting concept learning. The general conclusion is that personal epistemological beliefs mediate concept learning. For studies using modified versions of the SEQ, it was found that the most influential epistemological beliefs are those related to beliefs about certainty and structure of knowledge. Relevant discussions can be found in the works of Lodewyk (2007), Sinatra et al. (2003), and in an earlier work by Windschitl and Andre (1998). Among other studies, beliefs about the process of learning, the goal of learning (e.g., Chu and Treagust 2008; Watters and Watters 2007), and learning from authority (Sinatra et al. 2003) are also shown to affect concept understanding. Moreover, Nussabum et al. (2008) used the EBA to show that epistemic beliefs related to judgmental criteria affected conceptual change.

For those analyzing domain-specific epistemological beliefs, Tsai (1998b) found that students' scientific epistemological beliefs were significantly related to the recall and structure of knowledge derived from instruction of basic atomic theory. By analyzing weekly reports, David May and Eugenia Etkina (2002) showed that physics students' epistemological reflections on learning were associated with conceptual gains. Stathopoulou and Vosniadou (2007) found that beliefs about construction and stability of physics knowledge and beliefs about the structure of physics knowledge predicted physics concept understanding. It should be noted that the science subjects involved in these studies are largely related to biology and physics.

Psychomotor Domain: Strategy and Skill Learning

As mentioned, another domain of science learning is the psychomotor domain, which is related to skill and strategy learning. According to our analyses of the selected papers, two prominent competencies in the psychomotor domain are learning strategies/approaches and reasoning skills. In our collection of papers, six studies discuss associations between epistemological beliefs and learning strategies or approaches. These works are described in the following paragraph.

Tsai (1998a) found that students with a constructivist-oriented epistemology of science tended to adopt more meaningful learning strategies. In the work of Mark Windschitl and Thomas Andre (1998), students with more sophisticated epistemological beliefs seemed to have better explorative strategies when given implicit instruction about how to use simulation. Further, Hogan (1999) found that students' epistemological perspectives interacted with their sociocognitive engagements in the collaborative learning task. More recently, Heinz Neber and Marlene Schommer-Aikins (2002) demonstrated that science-related self-efficacy and epistemological awareness predicted the use of regulatory strategies in science learning while Watters and Watters (2007) showed that many students in their study held a highly dualist perspective about knowledge and described approaches to learning or learning strategies that emphasized rote learning and memorization. Furthermore, they noticed that high-performing students who displayed beliefs about learning and knowledge that reflected sense-making and relationships in the learning process and the relevance and connectedness of ideas, tended to employ constructivist-oriented learning strategies. Moreover, Lourdes Rodriguez and Francisco Cano (2007) found that students who had more mature beliefs about knowledge and learning adopted approaches representing deeper ways of learning. Overall, empirical findings suggest that learning approaches were associated more with epistemological beliefs regarding structure of knowledge, knowledge construction, justification of knowledge, learning process, and intention of learning.

In the context of science, argumentation represents the core of the scientific activity (Newton 1999). Thus the improvement of argument skills is taken as an important aim of science learning. In schools, there seems to be a common belief among many teachers that the fluent use of the logic rules in science classrooms can be transferred to everyday contexts. However, empirical research has not confirmed this. For example, many studies showed that when placed in life contexts, even educated adults could not make sound scientific arguments (e.g., Jiménez-Aleixandre and Pereiro-Munoz 2002; Kuhn 1991). While some studies point out that the performance of scientific reasoning has much to do with the acquisition of domain-specific knowledge (e.g., Yang and Anderson 2003; Zimmerman 2000), other studies show that the influence of domain-specific knowledge is not clear particularly when the problem in discussion is ill-structured by nature (Perkins 1985; Means and Voss 1996).

Kuhn (1991) has shown that use of argument skills in everyday contexts appears to be predicted by a level of epistemological understanding, and Michael Nussbaum and Lisa Bendixen (2003) discovered that personal epistemological beliefs predicted avoidance of arguments. A cross-age study conducted by Michael Weinstock, Yair Newman, and Amnon Glassner (2006) revealed that older high school learners with greater epistemological sophistication identified more informal reasoning fallacies. A similar result was obtained among college students (Ricco 2007). In short, the studies reviewed indicated the developmental relation between argumentation in general contexts and personal epistemology.

In our collection of studies, there are five papers placing argumentation in the context of science learning. William Sandoval and Kelli Millwook (2005) reported that although high school students were attentive to the need of evidence for supporting claims, they failed to articulate how specific data related to particular claims when engaged in a scaffolding inquiry-based science instruction. They concluded that the quality of argument is linked with learners' epistemological understanding about warrants and data. When examining eighth grade students' argumentation skills in reasoning about science-related controversial issues, Lucia Mason and Fabio Scirica (2006) showed that epistemological understanding about knowledge and knowing is a significant predictor for making arguments, counterarguments, and rebuttals. Recently, Michael Nussbaum et al. (2008) reported that epistemic beliefs about knowledge and knowing (judgment of knowledge in particular) affect students' learning of scientific argumentation. Yang and Tsai (2010) also found that the performance of argument skills was more associated with epistemological beliefs about certainty of and justification for knowledge.

As far as learning and improvement of argumentation are concerned, by analyzing performances of scientific reasoning across different ages of students (sixth, eighth, and twelfth grade students), Yang and Tsai (2010) proposes a developmental model that showed the interplay between the development of epistemological beliefs and improvement of scientific reasoning. It has also been demonstrated that a one-year-long socioscientific issue (SSI) instruction emphasizing argumentation and discourse advanced students' epistemological beliefs concerning concepts of knowledge and justification (Zeidler et al. 2009).

In sum, the studies reviewed imply that the most critical epistemological dimensions that mediate argumentation in science are the nature of scientific knowledge and justification for knowing. The curriculum that allows learners to reflect on personal beliefs about certainty of knowledge and the process of knowledge construction will have better chance to improve scientific argumentation.

Affective Domain: Learning About the Nature of Science

An equally important goal of science education is to promote learners' appreciation for the interdependence of science and society. To this end, students must be introduced to and gradually develop the beliefs, values, and attitudes that are highly respected in the community of science. The nature of science is, in general, described as a way of knowing or the values and beliefs inherent to the development of scientific knowledge (Lederman and Zeilder 1987; McComas et al. 2000). Thus, teaching and learning the nature of science (NOS) have become critical components of science education programs that reflect the affective domain of science learning. In the literature, considerable efforts have been made to develop NOS-rich curricula. However, the effects of such curricula to change or improve understanding about NOS are not always positive (Lederman 1992). In recent years, the role of epistemological beliefs in mediating the learning and understanding about the NOS has gained attention of more and more science educators.

For example, Tsai (1999a) shows students with constructivist and empiricist views about science hold different perceptions about science laboratory activities.

Michael Enman and Judy Lupart (2000) reveal that an individual's beliefs about the nature of knowledge and learning predict his or her commitment to science. In a review of studies exploring students' understanding about the NOS, Kathleen Hogan (2000) argued that learners' personal epistemological beliefs in science, and perceptions about learning derived from experiences of school science learning, interact with their understanding about the nature of professional science. Yang (2005) found that the higher epistemological position, the better the understanding about the role of expert and evidence in science. In summary, empirical studies as listed in this section suggest that the difficulty of enhancing learners' understanding of the NOS could have resulted from the fact that they have not developed compatible epistemological beliefs.

Suggestions for Future Studies

In this chapter, we have reviewed 37 empirical studies that explore relations between personal epistemology and science learning. Based on our analyses, research on personal epistemology in the context of science learning consists of three aspects of beliefs with respect to the nature of knowledge, knowing, and learning. Dimensions of beliefs about the nature of knowledge include certainty or stability, structure, and forms of scientific knowledge. Construction of scientific knowledge, source of scientific knowledge, justification of knowledge, and nature of scientific method, activity, and community are frequently mentioned dimensions of beliefs about the nature of knowing. As far as dimensions of beliefs about learning in science are concerned, goals of science learning, processes of learning different disciplines, and ideal science learning environments are the main categories.

As discussed earlier, both domain-general and domain-specific instruments were utilized to examine beliefs about the nature of knowledge and knowing in science, but for beliefs about learning, only a few studies assessed student perceptions using domain-specific methods (Tsai 2004; Lee et al. 2008). Domain-general instruments allow science educators to draw a general picture about students' epistemological development. However, when it comes to instructional practice, detailed information about different learners' epistemological perceptions in different classroom settings is required. Thus, we expect more studies discussing the developments and the uses of domain-specific instruments for assessing students' beliefs about learning of different science subject matters. Moreover, science learning is a complex process that is individual, social, and culturally relevant. Current existing studies probe mostly beliefs at the individual level. Therefore, studies that examine beliefs about science learning in the social and cultural context are desirable.

As presented in this chapter, the role of personal epistemology in mediating concept learning in science is widely agreed. However, longitudinal effects have not been thoroughly studied. In addition, it has been shown that concept learning in science as indicated in the selected studies was mostly discussed in the contexts of biology and physics. Further studies are needed to explore learning in different scientific disciplines.

As for learning approaches, the selected studies in this chapter have confirmed that different forms of personal epistemology induce different learning approaches. Although these studies were conducted in various subject areas, similar correlational patterns between personal epistemology and learning approaches were found (e.g., the higher epistemological status, the more constructivist-oriented the approach). For future studies, more attention should be placed on analyzing the complex interplays among the instructional designs, personal epistemology, and learning approaches. Such studies will provide science educators with more information about how to create beneficial classroom settings for different learners.

Developing a science learning environment that supports and promotes argumentation has become an important objective of practice for science educators. According to Richard Duschl and Jonathan Osborne (2002), one of the necessary components of such instruction is exposing learners to epistemological criteria of argumentation in science. As discussed in this chapter, the selected studies argue that learning of argument skills is greatly influenced by personal epistemological beliefs. Thus, as Yang and Tsai (2010) mentioned, while it is critical to introduce students to the epistemological criteria of science, taking into account epistemological development, instructors should at the same time encourage children to reflect on their own epistemological thoughts rather than force them to accept the formal epistemology of science. In fact, some researchers have started to take notice of the design of epistemology-based science instruction (e.g., Yang and Tsai 2010; Zeidler et al. 2009). In the future, more experimental studies are needed to analyze the designs and the effects of such instructions.

Lastly, it has been mentioned that most of the epistemological studies in science learning involved mainly students at high-school or university levels. Given that the development of personal epistemology is an on-going process that is shaped by educational experiences, more studies with elementary school learners are necessary to clarify the developmental characteristics about personal epistemology in the context of science learning.

Appendix Summaries of research methods, epistemological instruments, and dimensions of epistemological beliefs for empirical studies regarding personal epistemology and science learning (the papers are listed in alphabetical order of authors)

#	Paper	Methodology	Epistemological instruments	Dimensions of epistemological beliefs
1.	Chan and Sachs (2001)	Quantitative study with 46 grade 4 and 37 grade 6 students	Implicit Learning Survey	Shallow view about learning vs. deep, constructivist view
2.	Chu and Treagust (2008)	Qualitative study with 10 freshmen	Interviews	1. Beliefs about physics knowledge 2. Beliefs about learning physics
3.	Conley et al. (2004)	Quantitative study with 187 fifth graders	Elder's (2002) Epistemological belief about science questionnaire (EBS)	1. Source 2. Certainty 3. Development 4. Justification
4.	Enman and Lupart (2000)	Quantitative study with 151 undergraduates	Schommer's (2002) Epistemolgy Questionnaire (SEQ)	1. Quick learning 2. Fixed ability 3. Simple knowledge
5.	Hogan (1999)	Qualitative study with 12 eighth graders	Interview	Nature of theory development and change in science: 1. Inductivist 2. Realist 3. Relativist
6.	Hogan and Maglienti (2001)	Mixed method: qualitative (interviews) and analyses with 24 eighth graders, 21 adults (16 science professionals and 5 nonscience majors)	Evaluations on 10 conclusions that hypothetical students (HS) made based on a given body of evidence	Epistemological criteria: 1. Coherence with personal inferences from the data 2. Coherence with prior knowledge, beliefs, or values 3. Specificity of conclusions
7.	Leach et al. (2000)	Qualitative study with 731 high school students and university students	Five written survey items including (3) contextual and (2) decontextual questions	1. Data focused reasoning 2. Radical relativist reasoning 3. Knowledge and data-related reasoning

8.	Lee et al. (2008)	Quantitative study with 474 high school students	Conception of Learning Science (COLS) questionnaire	1. Memorizing 2. Preparing for test 3. Calculate and practice 4. Increase of knowledge 5. Applying 6. Understanding and seeing in a new way
9.	Liu and Tsai (2008)	Quantitative study with 220 freshmen majoring in science, nonscience, and science education	Scientific Epistemological Views (SEV) Questionnaire	1. Role of social negotiation 2. Invented and creative nature of science 3. Theory laden exploration 4. Cultural impacts changing a 5. Tentative feature of scientific knowledge
10.	Lodewyk (2007)	Quantitative study with 447 tenth graders in science classes	SMEQ (Schommer's Modified Epistemology Questionnaire)	1. Fixed ability and quick learning 2. Simple knowledge 3. Certain knowledge
11.	Mason and Scirica (2006)	Quantitative studies with 62 eighth graders	1. Kuhn's Epistemology Assessment (EA) 2. Qualitative analysis for reasoning	Beliefs about knowing and knowledge 1. Absolutist 2. Multiplist 3. Evaluativist
12.	May and Etkina (2002)	Qualitative study with 12 physics students	Journal writing	Beliefs about the nature of physics knowledge 1. Applicability of knowledge 2. Concern of coherence

(continued)

Appendix (continued)

#	Paper	Methodology	Epistemological instruments	Dimensions of epistemological beliefs
13.	Neber and Schommer-Aikins (2002)	Quantitative study with 93 elementary students and 40 high school learners	1. SEQ (Schommer 2002) 2. Epistemological Intentions (EI, Neber 1993)	1. Beliefs in innate inability for knowing 2. Belief that success is unrelated to work 3. Belief in quick learning 4. Belief in seeking single answers 5. Belief in avoiding integration of knowledge 6. Belief in certain knowledge
14.	Nussbaum et al. (2008)	Quantitative study with 88 university students in the major of educational Psychology	Kuhn et al.'s Epistemic Beliefs Assessment (EBA)	1. Judgments of taste 2. Aesthetic judgments 3. Value judgments 4. Judgment of truth about the physical world 5. Judgment of truth about social world
15.	Park (2007)	Qualitative study with 7 high school students	Interview	1. Epistemological commitment: truth of knowledge, justification for knowing 2. Metaphysical beliefs: meta-physical beliefs, i.e., beliefs in the ultimate existence of qualities or properties of objects or phenomena 3. Nature of knowledge 4. Nature of learning 5. Nature of conception

16.	Rodriguez and Cano (2007)	Quantitative study with 173 freshmen, 215 senior, and 81 longitudinal	Epistemological Questionnaire (EQ)	1. Belief in quick learning 2. beliefs that knowledge is unambiguous and handed down by authority 3. Beliefs in fixed ability 4. Beliefs in certain knowledge
17.	Roth and Lucas (1997)	Qualitative study with 23 students in junior-level physics course	1. Structured and unstructured essays 2. Interviews 3. Class discussions	Nine interpretive repertoires (discursive resources) Intuitive, religious, rational, empiricist, historical, perceptual, representational, authoritative, and cultural resources
18.	Sandoval (2003)	Qualitative study with 69 in 23 groups (19 valid) of high school students	Electronic journal	Causation in explanations Nature of data
19.	Sandoval and Reiser (2004)	Qualitative study with 69 high school subjects	Electronic journal	Epistemic practices: 1. Epistemologically oriented mentoring – monitoring progress 2. Planned investigation 3. Negotiating explanations 4. Evidence evaluation 5. Recognizing important data
20.	Sandoval and Morrison (2003)	Qualitative study with 8 high school students	Interview	1. Goals of science 2. Types of questions scientists ask 3. The nature of experiments, hypothesis, and theories 4. Influence of theories and ideas on experiments 5. Processes of theory change

(continued)

Appendix (continued)

#	Paper	Methodology	Epistemological instruments	Dimensions of epistemological beliefs
21.	Sandoval and Millwook (2005)	Qualitative study 87 students high school students	Electronic journal	Levels of understanding about data/evidence to support claims
22.	Sinatra et al. (2003)	Quantitative study with 93 college students	SEQ (Schomme's 25-item version SEQ developed by Kardash and Scholes 1996)	1. Seek single answers 2. Don't criticize authority 3. Ambiguous information 4. Dependence on authority 5. Certain knowledge
23.	Stathopoulou and Vosniadou (2007)	Quantitative study with 394 tenth graders	Greek Epistemological Beliefs Evaluation Instrument for Physics, (GEBEP) for	1. Structure of knowledge 2. Stability of knowledge 3. Source of knowing 4. Justification of knowing
24.	Tsai (1998a)	Mix of quantitative and qualitative methods with 5000 junior high students	1. Pomeroy's (1993) questionnaire 2. Interview (SEB and learning orientations)	Empiricist vs. constructivist perspectives
25.	Tsai (1998b)	Mix of quantitative and qualitative methods with 202 students (48 were selected for flow-map)	1. Pomeroy's (1993) questionnaire 2. Flow-map for assessing cognitive structure	Empiricist vs. constructivist perspectives
26.	Tsai (1999a)	Mix of quantitative and qualitative study with 86 eighth graders	1. Pomeroy's (1993) Questionnaire 2. Observations on social interactions (discourses) 3. Science Laboratory Environment Inventory Interviews	Traditional views vs. constructivist views of science

27.	Tsai (1999b)	Mixed method with 101 high school female students	Pomeroy's (1993) questionnaire Interview	Empiricist vs. constructivist perspectives
28.	Tsai (2000a)	Quantitative study with 1176 high school students	Pomeroy's (1993) questionnaire	Empiricist vs. constructivist perspectives
29.	Tsai (2000b)	Mixed method: quantitative and qualitative analyses with 101 tenth graders females	Pomeroy's (1993) questionnaire Interview	Empiricist vs. constructivist perspectives
30.	Tsai (2004)	Qualitative study with 120 eleventh and twelfth graders	1. Interview 2. Phenomenographic analysis	Conceptions of learning science
31.	Tsai and Liu (2005)	Quantitative study with 613 high school students and 19 teachers	Epistemological Views Toward Science (SEV)	1. Social negotiation 2. Invented and creative nature of science 3. Theory-laden exploration 4. Cultural impacts Changing and tentative feature of science knowledge
32.	Watters and Watters (2007)	Quantitative study with 85 university students	Semistructured interviews	Beliefs about knowledge and learning
33.	Windschitl and Andre (1998)	Quantitative study with 250 university students	Schommer's SEQ	1. Simple knowledge 2. Quick learning 3. Certain knowledge 4. Innate ability
34.	Yang (2005)	Mixed method with 71 tenth graders	Learning Environment Preference (LEP) Questionnaire Open-ended questionnaire	1. View of knowledge 2. Views about learning environments (instructors, peers, students, evaluations)
35.	Yang and Tsai (2010)	Qualitative study with 62 sixth graders	Interview	1. Certainty of knowledge 2. Source of knowledge 3. Justification of knowledge

(continued)

Appendix (continued)

#	Paper	Methodology	Epistemological instruments	Dimensions of epistemological beliefs
36.	Zeidler et al. (2000)	Qualitative study with 28 ninth and tenth graders, 119 eleventh and twelfth graders, and 101 college students	1. Open-ended questionnaires 2. Interviews	1. Tentativeness of scientific claims and why the claims change 2. Role of empirical evidence 3. Role of theoretical commitments, and social and cultural factors 4. Human creativity, imagination, and sociocultural-embedded factors
37.	Zeilder et al. (2009)	Qualitative study with about 120 eleventh and twelfth grade students	Interviews ($n = 40$) based on Reflective Judgment Model	1. Role of authority 2. Role of evidence 3. View of knowledge 4. Concept of justification

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Chapter 20
Science Learning and Epistemology

Gregory J. Kelly, Scott McDonald, and Per-Olof Wickman

This chapter examines the relationship of science learning and epistemology. We begin with the assumption that theories of learning necessarily presuppose views of knowledge. We consider how different theories of learning draw on epistemology, and how through the process of investigating science learning, researchers define their respective theories of knowledge. Traditionally, epistemology is a branch of philosophy that investigates the origins, scope, nature, and limitations of knowledge (Boyd et al. 1991). Thus, the interpretation of what is learned, how it is learned, and by whom, and under what conditions, poses epistemological questions for research in science learning. While this is a traditional definition of epistemology, studies of learning conceptualize epistemology in different ways for different purposes. We consider the ways that history and philosophy of science have informed learning theory (disciplinary perspective), ways that students' personal epistemologies influence learning (personal ways of knowing perspective), and emerging studies of practical epistemologies that consider ways that disciplinary practices are enacted interactionally in learning contexts (social practices perspective). We will consider how conceptions of knowledge are operationalized in science learning research and draw implications for research in science education.

In our review, we identify how these three different conceptualizations of epistemology are seen to influence science learning. Each view allows the respective researchers to view knowledge in a unique way and inform research from these perspectives. These views of knowledge are not necessarily mutually exclusive,

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but rather, each perspective places emphasis on certain aspects of epistemology, with less attention to other aspects. One view (*disciplinary perspective*) considers the important role of disciplinary knowledge for science learning. This position conceptualizes epistemology as a discipline concerned with examining issues such as the nature of evidence, criteria for theory choice in science, role of theory-dependence in scientific research methodology, and the structure of disciplinary knowledge (Duschl 1990; Grandy and Duschl 2008). The disciplinary perspective is a philosophical view of epistemology, largely normative in nature (i.e., it considers the reasons for theory change and the evidence relevant to such changes), focusing on knowledge within practicing scientific communities (Kelly 2008).

A second view of knowledge emanates from psychologically oriented studies of learning (*personal perspective*). These studies are concerned with the ways that individual learners conceptualize knowledge and how such personal views of knowledge influence their learning (Hofer 2001). Rather than offering a normative point of view, this psychologicalized view of epistemology, treats theories of knowledge as personal, empirical, and contingent. The focus is centered on internal representation of cognitive structures (Duschl et al. 1992), and personal views of truth, rather than on disciplinary considerations of rationality, truth, and justification. Studies consider normative approaches about how education should foster epistemological development and empirical studies that examine how personal theories of knowing influence further learning.

The third view of epistemology considers the social practices that determine what counts as knowledge in local, contingent contexts (Knorr-Cetina 1999). These studies do not view theories of knowledge as either extant disciplinary entities or solely personal views, but rather view knowledge as accomplished through social interaction. This *social practices* view of epistemology examines how, through particular learning events, questions of justification, reasonableness, and knowledge claims are negotiated among members of a group. This view describes the ways that being a member of an epistemic culture, observing from a particular point of view, representing data, persuading peers, engaging in special discourse, and so forth, locally define knowledge (Kelly 2008; Wickman 2004).

Each of the three perspectives offer expressive potential that defines the research programs in particular ways (Kelly and Green 1998). While the perspectives may show some overlap and mutual recognition, they represent some unique contributions to research in science education.

Disciplinary Perspectives on Science Learning

Philosophy of science has served as an intellectual referent for the development of science curricular materials and weighed heavily in thinking about the aims of science education (e.g., Duschl 1990; Schwab 1962). One example of this line of work would be conceptual change theory (Posner et al. 1982), which was based initially on theory-change models in scientific fields, and continues to benefit from epistemological analogies between scientists and science learners (e.g., Tyson et al. 1997;

Duschl and Hamilton 1998). Theory change in science offers ways to conceptualize the learning tasks for students and suggests ways of organizing knowledge to support learning. These perspectives are typically normative in nature, that is, they consider how rationality is defined and how concepts change through reasoning. For example, Nancy Nersessian (1992) identified a number of epistemologically relevant abstraction techniques (i.e., analogy, imagery, thought experiment, limiting case analysis) that can support student learning. The history and philosophy of science were central to the focus on conceptual change theory, and studies of science learning continue to progress toward interests in the ways that theories and models are developed, examined, and evaluated in both science and learning contexts.

A second way disciplinary perspectives have informed science education, concerns the process of legitimation. Both intended science curricula and their enactment are often informed by views of the discipline. While some curricula may be created with implicit views of science, or various disciplines within science, others specifically rely on philosophy of science. Obvious in this respect are efforts to teach about the nature(s) of science to change students' conceptions or images of the epistemology of science (Lederman 2007). A number of scholars, including Sherry Southerland, Gale Sinatra, and Michael Matthews (2001) and Derek Hodson (1988), have implored the field to consider the epistemological bases for choices about science curricula. For example, John Leach, Andy Hind, and Jim Ryder (2003) used the history of science as a framework to design units in electromagnetism and cell membranes to help students understand the status of scientific theories. Through careful curriculum design they were able to improve some students' epistemological ideas – that is, to a limited extent, the students were able to engage with scientific models and not just focus on collecting empirical data.

The disciplinary view of epistemology continues to be informed by a number of fields, beyond just history and philosophy of science, that consider the ways that scientific theory and knowledge evolve. Known collectively as science studies, these fields offer ways of reexamining and reevaluating science learning (Kelly 2008). Science studies include examining scientific communities from an empirical point of view through the study of practices in situ. The central contribution has been to move away from the presentations of final form science in classrooms to a focus on the consensus building dynamics present in knowledge-building communities (Duschl 2008). Such dynamics are rooted in the argumentative nature of scientific discourse, where evidence is considered within theoretical traditions. Science studies research points to the very social nature of consensus building in science fields and offers a valuable referent to consider changes in knowledge structure. Thus, while a focus on scientific theories and models developed in philosophy of science offers opportunities for students to understand certain aspects of the epistemology of science, science studies offer a view into the social and epistemic practices determining what counts as science. For example, Duschl (2008) identified how science studies can inform science learning by noting that scientific actions include building theories and models, constructing arguments, and engaging in the social languages of special communities. A shift to the practical actions of scientific communities offers the opportunity to integrate various cognitive and sociocultural views of learning into the design of science learning environments and curricula (Leach and Scott 2003). The focus on learning poses epistemological issues for personal ways of knowing and disciplinary practices, perspectives we examine in the subsequent sections.

Personal Epistemologies and Learning Science

The notion of personal epistemologies developed out of the work by William Perry (1970) regarding the intellectual development of college students. Personal epistemology research has since evolved in two primary veins: developmental stages and patterns of beliefs. Recently, there has been a movement to unite the stages and patterns of beliefs models and also to reconceptualize personal epistemologies. In general, the vein focusing on developmental stages examines the progression of beliefs from simple, certain, and dualistic (right/wrong) notions of knowledge, through relativist or uncertain subjectivity, and on to beliefs allowing for multiple views whose validity is considered in relation to context. Patricia King and Karen Kirchener's (1994) reflective judgment, for example, contains seven stages covering this continuum. In contrast, the research examining patterns of epistemological beliefs tends to take a broad view and include beliefs about intelligence and learning (Ken Lodewyk 2007), but views them as individual factors impacting a variety of correlates including motivation, cognitive development, conceptual change, self-efficacy, and task performance. Barbara Hofer (2004) has recently described epistemic metacognition, an attempt to unify the views of personal epistemology, which characterizes epistemic beliefs as theory-like patterns of belief that develop over time and are drawn on in more context-dependent ways.

Science learning has been informed in many ways by research from both the developmental and patterns of beliefs perspectives. Much of the focus of science learning has traditionally been on students' alternative conceptions and how, through systematically designed learning sequences, students can come to richer, more reason-based ways of understanding natural phenomena. Within this research framework, learners' ways of conceptualizing knowledge has been shown to influence science learning. Hofer (2001) characterizes this research as "personal epistemology" and notes the focus on "ideas individuals hold about knowledge and knowing" (p. 353). Within the focus on personal epistemologies, Orpha Duell and Marlene Schommer-Aikins (2001) identified five directions of research for personal epistemology studies: justification of knowledge, coping with uncertainty, gender issues, multiplicity of epistemological beliefs, and academic domain specificity. The general theoretical issues concern learners' beliefs about knowledge and how these beliefs change. Methodologically, this research tradition focuses on developing instruments to measure learners' beliefs about knowledge and learning (Duell and Schommer-Aikins 2001; Schraw 2001) and correlating them to a variety of other student factors.

In science learning contexts, learners' views of knowing and knowledge acquisition have been used to develop a framework for evaluating the authenticity of classroom science inquiry tasks (Chinn and Malhotra 2002). There have also been examinations of the alignment of students' personal epistemologies of science with those of their science teachers (e.g., Roth and Roychoudhury 1993). Furthermore, Andrew Elby and David Hammer (2001) noted that philosophically correct epistemological positions do not necessarily align with the heuristic value of certain epistemological beliefs. They identified how a sophisticated epistemology needs to consider relevant contextual information to make judgments about inquiry processes involved in learning through engagement with nature. It is clear that attention to students' epistemological views is important to an understanding of science learning; however, both the nature of these views and the relationship to science learning are not unambiguous.

Hammer and colleagues (e.g., 2003, 2008) have attempted to ontologically reconceptualize epistemic beliefs in much the same way that Andrea diSessa's (1993) knowledge in pieces did for misconceptions. Hammer suggests that epistemology should be considered in finer grained and context-specific form – epistemic resources. Students' views of knowledge are thus manifestations of those parts of the raw material activated within a particular context. Data from elementary school students' beliefs in physics are used to support this view (Hammer et al. 2008). Hammer's epistemic resources can be seen as a bridge from a highly situated, contextually bound personal view of epistemology to a sociocultural approach to epistemology – the notion of epistemology as a social practice.

Epistemology as Social Practice

Studying epistemology as social practice entails seeing epistemology as constituted through situated interaction. The aim is to describe actual epistemological practice, that is, how people proceed in action to accomplish certain purposes. This definition of epistemology is close to that of Richard Rorty (1991, p. 1), who maintained that we should not "view knowledge as a matter of getting reality right, but as a matter of acquiring habits of action for coping with reality". Studies of epistemology as social practices draw on sociocultural, ethnographic, and pragmatist studies of learning as talk and action in science classrooms. Jay Lemke (1990) is an early example of an analysis of the meaning given to science in classrooms through talk. Another example is Wolff-Michael Roth (1998), who studied the significance of social networks and artifacts for the meaning made in science classrooms. Also important are those experimental and interview studies examining the significance of artifacts and the communicative context for what students know (Edwards 1993; Schoultz et al. 2001). Although studies like these are not explicitly concerned with students' epistemologies, they demonstrate the holistic and empirical stance the social practice perspective has toward knowledge and learning and so toward epistemology. Within the social epistemology perspective, there is great variation regarding the nature and extent of the social in developing scientific knowledge, from relativist positions to those dedicated to examining the social basis for evidence use (Kelly et al. 1993).

Within this perspective, knowledge is seen as competent action in a situation rather than as correct, static representations of the world. To decide on what ways student actions are competent, they need to be examined in an activity with some human purpose. Hence, communication and action primarily has meaning within purposeful practice, in doing something (Kelly 2005; Wickman 2006). This tenet from Ludwig Wittgenstein (1967) is central for the epistemological analysis from this perspective (Lynch 1993). Epistemology as social practice is a description of how a community must continually construe what counts (Knorr-Cetina 1999). This means that we must study both science proper and school science as “science-in-the-making” (sensu Latour 1987, p. 4) to describe their epistemologies (Kelly et al. 1993). Only when we have these descriptions of how the participants themselves go about making sense can we suggest meaningful improvements from the educational researcher’s outside perspective (Kelly 2005; Wickman 2006). In science education research, description starts from that of school science-in-the-making without beforehand imposing outside analytical constructs such as positivism or constructivism on the patterned actions of students (Kelly and Crawford 1997).

Knowledge when studied in this way is encountered in transition as part of practice; continual learning is needed to transform knowledge to the contingences of each situation. Knowledge in this way is not propositional but enacted. However, the patterns of actions are not entirely contingent. They form certain jointly constituted discursive ways of dealing with people, objects, and events, and in particular ways of deciding what and whose knowledge counts (Kelly et al. 1998). Crawford et al. (1997) followed two bilingual high school students and studied the presentation of their science project across different audiences. The students’ descriptions varied across audiences such as teachers, classmates, and fifth-grade students. What counted as knowledge was construed depending on the communicative setting, suggesting that different communicative contexts afford students different ways of understanding what may first seem to be the same subject matter content. Hence, an ethnographic study from a first person perspective, although not normative in itself, can be used to inform our decisions in science education.

Studying epistemology as social practices can be used more directly to study how meanings concerning the nature of science are negotiated in science class. Gregory Kelly, Catherine Chen, and William Prothero (2000) developed such a method drawing from sociological and anthropological studies of scientific communities. Using this approach they analyzed talk and writing in a university oceanography class to examine such epistemological issues as the uses of evidence, role of expertise, relevance of point of view, and limits to the authority of disciplinary inquiry. Their study has implications for how epistemological issues can become an integrated part of science courses at the university.

Per-Olof Wickman and Leif Östman (2002a) and Wickman (2004) have developed a so-called practical epistemology analysis to study how certain meanings are made through interactions in science class as discursive practices. This approach can be used to study how different encounters with the teacher, among students, and between students and artifacts influence the direction learning takes through talk and action in a science class. Malena Lidar, Eva Lundqvist, and Östman (2005) examined how different kinds of epistemological moves by a teacher influence the learning of middle school students. An epistemological move is how the teacher directs the students in ways that determine what counts as knowledge and appropriate ways of getting knowledge in a specific school science practice. Wickman and Östman (2002b) studied the practical epistemologies of zoology students at the university to see to what degree students could use induction and deduction to produce testable hypotheses when making observations of real pinned insects. This study demonstrated that students' practical epistemologies were more experiential and holistic, using whatever they could apply from previous experiences to understand the structure of the studied insects. The situated and locally construed epistemology was shown to be more functional than the typical inductive and deductive stances to learning about insects. An analysis of high-school students' practical epistemologies in chemistry lab (Hamza and Wickman 2008) showed that learning was more influenced by local and contingent aspects of the situation than by the cognitive constraints implied from interview studies of students' misconceptions. It has also been demonstrated that the learning of science is not a merely a cognitive affair. When epistemology is studied as social practice it is clear that aesthetic judgments play a crucial role for what counts as knowledge. This was found in elementary school science, as well as in university science (Jakobson and Wickman 2008; Wickman 2006). Studying epistemology as social practice thus opens up possibilities to study learning processes that the personal perspective sees as mental entities (e.g., aesthetic experience, misconceptions) and to analyze how knowledge as action develops and is changed by the various experiences and other circumstances that meet in education.

In the social practice approach, conceptions and views are not primarily seen as something that determines action, but rather as units of action themselves. That a student repeatedly argues that 'science is tentative' is seen as a habitual way of reasoning, rather than a propositional personal understanding that causes certain ways to talk and act, which could be described by this propositional statement. William Sandoval (2005) borrowed the term practical epistemology from Wickman and Östman (2001) to designate a belief about knowledge in school science that influences students' ways of doing science inquiry in school. However, approaching epistemology as social practice or as practical epistemology in the original sense of the word does not assume that beliefs necessarily are the reasons why people have certain habitual ways of doing things (Wickman 2004). It might simply be the way they do things, without further reflection. It then becomes an empirical question as to why certain social practices develop and how they might be made more purposeful based on what we value in science education (e.g., McDonald and Kelly 2007; Sensevy et al. 2008).

Evolution of Epistemological Perspectives on Learning in Science Education

Learning theories in and informing science education recognize the importance of epistemology. Disciplinary, personal, and social practice views each offer unique and potentially complementary views about how knowledge and learning interact in science settings (Sandoval 2005). Across the different perspectives some common themes emerge. First, increasingly, science education researchers are viewing meaning as public, interpreted by participants (and analysts) through interaction of people via discourse including signs, symbols, models, and ways of being. Second, learning is increasingly examined through the everyday social practices of members of a group, for example, school settings, museums, research laboratories, and so forth. This research draws on the social knowledge of analysts to consider the ways that science is framed through discourse practices (Lundqvist et al. 2009). Thus, the measure of learning is not the results of student performance on tests, but rather how students are able to use language in authentic social settings (e.g., McDonald and Kelly 2007; McDonald and Songer 2008). Third, the epistemology is interpreted, not only in the traditional sense, concerning the origins, scope, nature, and limitations of knowledge, but as an interactional accomplishment among members who define for themselves what counts as knowledge in a particular context. Thus, the interactional nature of competent actions taken by members of a group in a situation comes to define knowledge. This view suggests that knowledge be examined as it occurs in practical actions, rather than as measured by students' decontextualized views of epistemology, nature of science, and so forth. Thus, through interaction with the world and each other, members of communities come to define what counts as knowledge, evidence, explanation, and so forth, and embody an epistemology through such actions. Finally, across the perspectives, the evolving nature of disciplinary knowledge and the confluence of perspectives on learning, suggest a focus on the epistemic moves made by teachers (Lidar et al. 2006). Further study of the different ways the teacher directs the students regarding what counts as knowledge is needed to develop desired learning situations for their students (Hammer and Elby 2003; Jiménez-Aleixandre and Reigosa 2006).

Future Directions for Studies of Epistemology and Learning

Our review of research involving epistemology and learning suggests that the emerging research directions draw from and are informed across perspectives. These perspectives may be mutually supportive, or in some cases, offer divergent directions for research and importantly, research methodology. There is fertile ground for additional studies in each area. However, there are also numerous directions that could plausibly emerge from the current knowledge base. We propose three for consideration. First, sociohistorical activity theory (CHAT) offers a direction that takes serious disciplinary knowledge and the acculturation associated with learning, and recognizes the need to examine knowledge in practice (Leach and Scott 2003; Van Eijck et al. 2009). Van Eijck et al. (2009) provide a cogent view of how measures of "students' 'images of science'" (p. 612) represent a snapshot of students' responses to research instruments and offer little insight into how students can engage in collective practices. In contrast, drawing from CHAT, they examine instead the coproduction of students' images of science at a moment in time, embedded in a particular context. This view suggests a methodological focus on the interactional accomplishment of science in an activity system. Second, drawing from the learning sciences, Duschl (2008) proposed a shift away from the unitary goal of conceptual understanding to a more balanced set of goals focused on the conceptual, epistemic, and social goals for science learning. Central to this view is the development of learning progressions, centered on the most core and generative concepts of the respective science disciplines – concepts that are learned through engagement in situated scientific practices (Leach et al. 2003). Importantly, these learning progressions include social and epistemic goals for assessing and evaluating the status of knowledge claims, methods, tools for measurement, and representations or models (Duschl 2008). Third, theories tying the epistemological moves of teachers to consequences for what counts as science for students offer a way to develop practical epistemologies in classroom conversations (Lundqvist et al. 2009). Across perspectives, we envision research that considers seriously the social, contextual, and contingent nature of epistemic activity associated with learning science.

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Part III
Teacher Education and Professional Development

Chapter 21
Science Teacher Learning

John Wallace and John Loughran

Introduction

The recognition of the central place of teacher learning in school reform is a recent phenomenon. As Marilyn Cochran-Smith and Kim Fries (2008) suggest, we have seen the evolution of teacher development from being seen as a curriculum problem (1920s–1950s) to a training problem (1960s–1980s) to a learning problem (1980s–2000s) to a policy problem (1990s–present). Over the past 20 years, there has also been a developing interest in the nexus between student learning and teacher learning (Sykes 1999) and the notion of teaching as a learning profession (Darling-Hammond and Sykes 1999). Building on the work of Peter Senge (1990) and others, the crux of this argument is that schools, more than most organisations, are in the business of learning, and that all members of the organisation, administrators, support staff, teachers and students, should operate in an environment where learning is actively and explicitly valued and supported. Rather than seeing teacher learning as the effect of teacher development, this new perspective sees learning as *both* effect *and* affect: teachers learn as students learn and students learn as teachers learn.

In this chapter, we focus our attention on science teacher learning. Our perspectives are informed by literatures from fields as diverse as psychology, sociology, teacher development, school effectiveness, curriculum change, organisational change, and science and mathematics education. We are interested in theories of teacher learning, the nature of science teachers' professional knowledge, science

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teacher learning through teacher research, the relationship between student learning and teacher learning, and the contexts for science teacher learning.

Theories of Teacher Learning

Theories of science teacher learning can be characterised by various images of teachers' work – including the metaphors of computer, craft and complexity (Mullholland and Wallace 2008). Under the *computer* database metaphor, the teacher is seen as a consumer of a wide range of discrete professional development offerings, with each offering being designed to add (or plug in) an additional component to the teacher's knowledge base. Such a model is contextually agnostic and knowledge acquisition is seen as a logical manipulation of symbols within the individual mind. Under the *craft* metaphor, the teacher is an independent artisan, gradually building a repertoire of practice-based knowledge and skills through cognitive apprenticeship. The *complexity* metaphor sees the teacher as a social being working in particular societal, school and classroom contexts and communities. According to Dominic Peressini and colleagues (2004, p. 69), knowledge acquired under this metaphor is specific to those settings and learning is viewed as 'changes in participation in socially organized activity'.

These three metaphors can also be viewed as points on a continuum between an individual-cognitive perspective in which knowledge and beliefs are the primary factors that determine action, and a collective-situative one in which 'knowledge and beliefs, the practices that they influence, and the influences themselves, are inseparable from the situations in which they are embedded' (Peressini et al. 2004, p. 73). Theorists from the individual-cognitive end of the range could include Jean Piaget (1965) (cognitive development), Fred Korthagen and Jos Kessels (1999) (gestalt theory), Ernst von Glasersfeld (1995) (radical constructivism) and, from the situative-collective end of the range, Lev Vygotsky (1978) (cultural-historical psychology), Jean Lave and Etienne Wegner (1991) (situated learning and communities of practice), Ralph Putnam and Hilda Borko (2000) (situated knowing), Marlene Scardamalia and Carl Bereiter (2003) (knowledge building), Edwin Hutchins (1995) (distributed cognition) and Paul Ernest (1998) (social constructivism). Concomitant approaches to teacher development include (from the cognitive end of the range) professional development workshops and conceptual change strategies, and (from the situated end of the range) problem-based learning, case methods, teacher self-study, action research and collaborative learning communities.

Science Teachers' Professional Knowledge

Learning theories and strategies aside, there is general agreement that science teachers' learning needs to focus on improving teachers' professional knowledge. The literature is replete with different ways of thinking about that which comprises teachers' knowledge (e.g. Clandinin and Connelly 1995; Fenstermacher 1994). Sandra Abell's (2007) review of research on science teacher knowledge illustrates how the shift from research *on* teachers (1960s and 1970s) to research *with* and *by* teachers (1980s) led to a serious focus on the nature of teachers' knowledge as opposed to how well teachers do their work. This shift led to a greater appreciation of teaching as something more than the simple delivery of information and highlighted the importance of knowledge of teaching in moving beyond transmission models of practice.

While there is much agreement about the importance of teacher knowledge, there is also considerable discussion and debate about how teacher knowledge is constructed, organised and used (Feldman 2002; Fenstermacher 1994). In a longitudinal case study of one teacher of science, Judith Mullholland and John Wallace (2008) attempted to portray a range of different, though related, teacher knowledge representations. As mentioned earlier in the chapter, the metaphors were

> … teacher knowledge as *computer*, whereby knowledge is viewed as an interactive database or sets of skills and understandings; as *craft*, whereby teachers are seen as artisans whose skills exist in accomplished performance against a backdrop of the teaching context; as *complexity*, whereby knowledge is developed in complex interaction with the total environment and inseparable from this environment; and as *change*, whereby knowledge grows, evolves or develops over time. (p. 42, original emphasis)

This study, like many others concerned with knowledge of teaching, inevitably involved the concept of pedagogical content knowledge or PCK (Shulman 1986, 1987). PCK, is 'subject matter knowledge for teaching' – an amalgam of knowledge of content and knowledge of practice, brought together in a particular way through the specialist teacher's expertise (Shulman 1986). As the literature continually demonstrates, PCK appears to resonate strongly with scholars concerned with researching knowledge of practice – but perhaps none more so than in science. PCK offers a lens into the complexity of science teachers' professional knowledge in ways that draw attention not only to teacher learning, but also to how that learning might be recognised in, and influence the development of, practice. In recollecting how he arrived at the concept of PCK, Lee Shulman explained:

> I understood how complex it was to teach and learn that set of [Biology] ideas … Because [in Biology] you've got to deeply understand what it is that makes evolutionary theory…, whether you think ecologically or cellularly, what makes it difficult, and then what the variety of misunderstandings students might have, with the resilience of their misunderstandings. … They'll pass your test and then three weeks later you… ask them to: 'Explain the idea of bacteria that develop a resistance to antibiotics' and they'll give you a classic Lamarckian interpretation. … There's a big idea that's sitting in the middle of the field [PCK is therefore evident in how a science teacher recognizes and responds to such a situation]. (Berry et al. 2008, p. 1276)

PCK has been interpreted and studied in many and varied ways (Gess-Newsome and Lederman 1999). However, despite its allure to academics, it only really makes sense to teachers when it becomes 'real' and moves from an abstract concept to a concrete, useable form of knowledge for practice. This is well demonstrated in the work of a number of scholars. For example, Appleton (Appleton 2006; Appleton and Harrison 2001) studied PCK in elementary teachers and illustrated how, for these teachers, PCK encompasses 'activities that work'. Likewise, PCK has been examined by van Driel and colleagues (1998, 2001) with pre-service chemistry teachers, by Pernilla Nilsson (2008) with pre-service elementary teachers, and by Kira Padilla and colleagues (2008) with university science teachers. Common to all of these studies is the way in which, through the lens of PCK, science teachers can learn about and, therefore, better value, their knowledge of practice.

A particular approach to making PCK concrete for science teachers is that of the CoRe (Content Representation) and PaP-eRs (Pedagogical and Professional-experience Repertoires), which were developed by a team of science education researchers at Monash University (Loughran et al. 2004, 2006). This approach has been successfully used in many studies of the knowledge of science teachers, but particularly so by Jim Woolnough (2007) in his work with pre-service teachers and Marissa Rollnick and colleagues (2008) with in-service teachers. In each of these studies, it is clear that participants frame their knowledge of teaching in new ways as a consequence of using a CoRe and PaP-eRs approach and situate themselves as learners and generators of knowledge of teaching. Such engagement in learning about teaching has been described by Robyn Brandenburg (2008) as reflective traction and can be a catalyst for more formalised inquiry into practice through teacher research.

Teacher Learning Through Teacher Research

Advocates such as Marilyn Cochran-Smith and Susan Lytle (Cochran-Smith and Lytle 1999, 2004; Lytle and Cochran-Smith 1991) have long argued that teacher research is an important cornerstone of educational reform. Although in many ways teaching might be described as involving ongoing inquiry into practice, it is through the more formalised approach of teacher research that teacher learning is able to move beyond the individual practitioner and be accessible and useful for others.

Many science teachers' initial forays into teacher research are as a consequence of apprehending the problematic in their own practice. John Wallace and Bill Louden (2002) drew attention to the problematic nature of teaching when they worked with science teacher researchers to explore the dilemmas of teachers' own practice through case writing. The notion of dilemmas is important because, as dilemmas are managed rather than resolved, teacher research based on dilemmas inevitably opens to scrutiny the myriad of decisions that teachers face in constructing meaningful learning experiences for their students. This work, like that of others working in the field of case writing (e.g. Lundeberg 1999; Shulman 1992) offers insights into one form of teacher research that begins to 'unpack' the complexity of teaching and learning.

Cases have proved to be an effective way of supporting and disseminating the learning from teacher research. For example, Berry and colleagues (2009) conducted a longitudinal study through which science teacher researchers published their cases. Berry's analysis suggests that, as a consequence of the careful attention to the detail necessary to write a case, many authors come to see into their classrooms in new ways, which itself then becomes an impetus for change. She illustrates how cases can empower teachers by opening up possibilities for dialogue about practice in ways that encourage and support risk-taking in practice – which is at the heart of learning from experience. Case reading and writing invites professional scrutiny and highlights the value of articulating knowledge of teaching which further supports teacher learning.

In a similar vein, Louden and Wallace worked with groups of teachers to focus on *specifics* (of teaching, often involving cases), on *standards* (of teaching and learning), on *quality conversations* (focused on teaching and with colleagues) and on *contexts* (structured formal and informal learning situations). In one example provided by Bill Louden and colleagues (2001), a group of experienced science teachers met regularly with academic collaborators over a 2-year period in a cyclic process of data collection, discussion and practice. Teachers videotaped their own classrooms, came together with colleagues to discuss their teaching videos in relation to a set of professional standards, and returned to the classroom to try some new ideas. The video segments, colleague commentaries and other artefacts were also assembled into a set of multimedia video cases for use as source material for further discussion.

Through case writing experiences, some science teachers have developed rigorous and systematic research into their practice and/or their students' learning. An example of this is to be found in the work of Ian Mitchell (1999), co-founder of the Project to Enhance Effective Learning (Baird and Mitchell 1986; Baird and Northfield 1992) and the subsequent Perspective and Voice of the Teacher (Loughran et al. 2002). These two influential projects involved science teachers documenting and learning from their own practices and collaborating in the hope that the same might happen for others. As a teacher researcher, Mitchell recognised that

> [t]eachers want to see classrooms via credible, contextually rich accounts of specific incidents … that provide teachers with ways into either experiencing the problem (e.g., ways of uncovering students' alternative conceptions in science) or into starting to do something about it. The accounts need to provide advice and ideas that will allow readers to experiment at different levels of risk. Accounts that gloss over difficulties and present stories of unmitigated triumph are unlikely to be credible to teachers… Communicating teacher research, in accessible and useful ways to other teachers involves some very different issues from those associated with communicating the same research to academics. (Mitchell 2002, pp. 263–264)

A common theme that emerges from teacher research is the value of teachers listening to, and therefore learning from, their students. The connection between science teaching and science learning should be such that they are not separate and distinct activities but partners in a symbiotic relationship. Therefore, just as it is anticipated that students learn from their teachers, so too it should be expected that science teachers learn from their students.

Teacher Learning Through Student Learning

Any serious examination of the notion of teacher learning must consider the reflexive and synergistic relationship between students' learning and teachers' learning. There are two ways to approach this subject, from science teachers to their students (as has been attempted by Kwang Yoon and her colleagues, 2007) or from students to their teachers. Here we chose to focus on the latter approach, that is, how science student learning can influence science teacher learning. The starting point for this approach is student science learning.

In their review of students' understanding of science concepts, Phil Scott et al. (2007) explained the roots of the field of 'alternative conceptions', moving from Piaget through to the influential work of Ros Driver (1983) and Roger Osborne and Peter Freyburg (1987). Much of the learning from this field has been captured in Helga Pfundt and Reinders Duit's (2000) *Bibliography: Students' alternative frameworks and science education*. However, knowing about students' conceptions, and doing something about it in practice are not necessarily the same thing.

In the final chapter of their influential book, *Learning in science: The implications of children's science*, Roger Osborne and Peter Freyberg (1987) consider what it means to introduce children's ideas of science to teachers.

> When we have talked to fellow teachers and teacher educators … [Some colleagues] have initially found it difficult to accept that their assumptions about what children interpret from their well-prepared lessons could be so different from what they (as teachers) intended. … When teachers become aware of children's ideas on the consequential difficulties pupils can have in learning science, they experience conflicting feelings as to what they can do about it. (p. 136)

Helping teachers to find appropriate ways of responding to children's ideas was the focus of the Children's Science group, initiated by Dick Gunstone (1990). The group was comprised of elementary and secondary science teachers who met on a regular basis with academic collaborators. Over a decade of work, the group developed and documented new teaching procedures designed to approach practice by taking into account students' prior views and/or to challenge students' thinking about science phenomena.

As the work of the Children's Science group demonstrated, listening to and learning from students focuses attention on the notion of meta-cognition:

> [Metacognition is the] amalgam of learner knowledge, awareness and control of their learning … [it] is learned, and so can be reconstructed if the learner is willing and able. It is not, however, in any way easy to have learners do this. It requires recognition of existing views, evaluation of these views, and then learner decisions about whether or not to reconstruct. … If the learners' ideas and beliefs about the processes of learning and teaching are in conflict with them recognizing, evaluating, reconstructing their existing science ideas and beliefs then little progress is possible. (Gunstone 1990, p. 17)

Meta-cognition is important not only to student learning but also to teacher learning. Clearly, just as students need to act meta-cognitively if they are to confront and reconstruct their conceptions of science, so too science teachers need to pay careful attention to that which is occurring in a classroom situation and to actively respond to what they see, hear and do, in a pedagogically appropriate way. Being sensitive to the 'student voice' is a fundamental element that underpins quality in science teaching.

Similarly, Robin Millar (2006) draws attention to the value of inviting students into their own learning of science through the notion of engagement. He suggests that, through a careful consideration of engagement, teachers can facilitate students' science learning by helping them to make powerful links between the science that they learn in school and the science that they know about from their out-of-school experiences. Again, the importance of recognising the synergies in teaching and learning are crucial here as exemplified Keith Bishop and Paul Denley's (2007) book. In their chapter on 'student voice', the authors show how science teacher learning is inextricably linked to learning from students:

> Our view is that it would seem odd to make no attempt to find out, or even be aware of, what the students you teach think of their science education or what they expect from it. … [T]he evidence suggests that the student voice offers exciting possibilities to innovative and creative science teaching and enhanced student engagement. From our own research, and from research in the public domain, we advocate that listening to students is an essential part of any science teacher's professional learning. (pp. 167–168)

It naturally follows that the way in which the practice setting is organised and structured influences not only how teachers learn, but also what they learn and what they do as a consequence of that learning. Therefore, the contexts in which teachers work and learn require just as much attention as the nature of that learning if the conditions for learning are to be supported and enhanced.

Contexts for Teacher Learning

What are the appropriate contexts for teacher learning? How can science teacher learning be nurtured and encouraged? For a simple answer to these questions, we might look at the recent empirical literature on 'reform' style teacher development to identify characteristics such as connection to the classroom, sustainability, collective participation, focus on content and student inquiry, active learning and coherence (Garet et al. 2001).

Another approach is to examine the typologies of teacher development strategies suggested by the individual-cognitive and the collective-situative, with the individual typified by out-of-school and workshop-style offerings and the collective characterised by in-school and collaborative activities. The advantage of the individual approach is that generalised solutions to curriculum problems can be identified and widely disseminated. Further, teachers can pick and choose offerings depending on their perceived needs and motivations. The disadvantage is that these activities are typically not grounded in the teacher's practice, and are often conducted in isolation from the communities that they are intended to serve. While collective approaches are more locally effective, they are often complex and unwieldy and suffer from a lack of transferability. However, as Dominic Peressini and his colleagues (2004) point out, the individual-collective dichotomy is misleading because the relationship between classroom practices and individual reasoning is reflexive. 'Students contribute to the development of practices within the classroom; these practices, in turn, constitute the immediate context for [teachers'] learning' (p. 71).

A further dimension to this discussion is offered by Lee Shulman and Judith Shulman (2004), co-investigators of the Fostering Communities of Learners programme. In attempting to fathom and explain the different learning experiences of two Grade 8 science and mathematics teachers, the authors concluded that, in order to learn, a teacher must be 'Ready (*possessing vision*), Willing (*having motivation*), Able (*both knowing and being able "to do"*), Reflective (*learning from experience*), and Communal (*acting as a member of a professional community*)' (Shulman and Shulman 2004, p. 259, original emphasis). As the authors point out, these attributes – readiness, willingness, ability, etc. – have both an individual and a collective component. 'The individual and community levels are both interdependent and interactive' (p. 267). They conclude: 'While the "subject matters" in these settings, there is so much more going on simultaneously that at times the ever-important content differences can be swamped by other critical features of the context' (p. 269).

Like many other scholars, we favour a pragmatic model of teacher learning that incorporates both theoretical positions. Paul Cobb and Janet Bowers (1999) talk about the 'choice between any particular case being a pragmatic one that depends on the purposes at hand' (p. 6). Such a position highlights the interrelatedness of elements within systems, and the notion of 'individual-in-social-action' used by Gary Hoban (2002) to represent the interaction of the cognitive and the situated.

A pragmatic perspective would suggest that teachers need the opportunity to engage in authentic activities, participate in rigorous and critical debate within discourse communities, and develop facility with the various tools used in that community. Often, these conditions are not always available in the one place. While authentic activities are most often associated with the classroom and the school, it is difficult for teachers to break out of routine ways of teaching, especially as schools do not always value or support critical and reflective practice. The more sophisticated cognitive, cultural and language tools of practice are often to be found in discourse communities outside the school – for example, in professional associations, universities and district and central offices. Moreover, organisational learning and learning across the profession are more likely to proceed if teachers also engage in communities beyond the four walls of the classroom.

We argue that supporting teacher learning entails the creation of formal and informal opportunities for learning to proceed in multiple contexts (settings, communities and learning foci). Deborah Ball and David Cohen (1999, p. 25) refer to a 'pedagogy of professional development' that comprises of the tasks and materials of practice, the discourse to support learning with these tasks and materials, and the roles and capabilities of leaders who provide guidance and support for this work. In this chapter, we have provided several examples of locally managed teacher development linked to other discourse communities, such as universities and school boards. The strength of these systems models is in the bringing together of the various components of the science education enterprise – students, teachers, teachers' knowledge, school leaders, research-based inputs, academic and systemic supports, etc. – in such a way as to build local relevance and ownership while developing both individual and organisational learning.

Conclusion

Teacher learning is, we maintain, a central tenet for educational reform. In this chapter, we argue for a model of teacher learning that encompasses both the individual-cognitive and the collective-situative stances on learning. This position recognises that teachers operate as individuals, making choices about levels of engagement, processing information and reflecting and acting on that information. Also teacher learning is inextricably linked to the learning of others – to students' learning, colleagues' learning and organisational learning.

We favour an approach to teachers' learning that focuses on research with and by teachers, on building teachers' knowledge about teaching and for practice, and capitalises on the inextricable connection between teachers' learning and students' learning. Such learning takes place in multiple learning contexts, combining out-of-school activities, theory and practice-based learning experiences with ongoing support for teachers to learn from their students and to integrate ideas into their classroom practice. In this chapter, we have described some promising examples of teacher learning, including action research projects, case writing, video clubs and content representation among others. These models have individual and collective components. They foster classroom-based, teacher research within a context of theory-driven ideas and collegial and other support. They also attempt to build a discourse community around science education, not only across the school but also in the wider school community.

Simply stated, teacher learning is about teachers building and sustaining knowledge of classroom practice across various discourse communities. It includes principles such as teacher ownership, focus on practice, coherence, collegiality, active learning and systemic support. Putting these principles into practice, however, is a different story. Teacher learning is complex because it is about the complicated interplay between the individual and the collective. In this chapter, we have argued for a model of teacher learning that acknowledges this complexity, and that marshals the various components of the science education enterprise to respect and support teachers' attempts to build knowledge of their own practice.

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Chapter 22
Teacher Learning and Professional Development in Science Education

Shirley Simon and Sandra Campbell

The Institute of Education in London hosts one of the nine Science Learning Centres set up in England in 2004 to promote the professional development of science teachers in each region of the country. The Centres are part of a government initiative to enhance science teaching and learning and offer Continuing Professional Development (CPD) courses that are perceived to be most needed by teachers. A CPD course could focus on technical aspects of teaching science, such as practical procedures, or more fundamental pedagogical practices, such as formative assessment. Courses may be just 1 day, or 2–3 days over a period of time with teachers taking ideas and activities to try out in their schools so that they can reflect and subsequently feed back ideas to colleagues on the course. A model of professional development that entails teachers coming out of school to attend short courses may be limited in its impact on pedagogy, even though such a model is financially and organisationally the most viable. Our concern as Institute researchers is to work in partnership with the Centre, sharing our research findings on teachers' response to innovations to develop a greater understanding of what makes professional development effective. Recently, the Centre has initiated outreach activities in schools in response to science departments requesting such support whilst they attempt to initiate fundamental changes in practice, such as assessment, and these are tailored to be more relevant to teachers' contexts and needs. Our ongoing research, informed by the wider international literature on professional development, attempts to explore other models of professional development that can enrich the work of the Centre.

This chapter presents a review of the literature that has informed our perspective and research on teacher learning and professional development. We address some questions that help to clarify our perspective and discuss models that have informed

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our work. We also draw on our own research on professional development to illustrate practices that provide insights to the success and limitations of professional development design.

What Do We Mean by Professional Development?

In 1996, Beverley Bell and John Gilbert published a book called *Teacher Development: A Model from Science Education*. The model they proposed was based on a 3–year study documenting how a group of New Zealand science teachers changed as they implemented new teaching approaches that would take account of students' existing thinking. The study arose from substantial research into children's ideas and learning in science (Osborne and Freyberg 1985) and constructivist views of learning (Osborne and Wittrock 1985), which had implications for teachers' roles and activities in science classrooms. Essentially, teachers were challenged to change their teaching from a process of transmitting knowledge to a process of helping students to construct scientific knowledge through questioning and testing existing ideas, engaging in different activities and contexts for learning, and reflecting on learning. Bell and Gilbert based their model on a view of learning that takes into account human development and the development of self-identity, social constructivism, and reflective and critical enquiry. The model portrays teacher development as taking place in three intertwined domains, the personal, professional and social, and identifies how progress occurs in each of these three domains. What makes this model so relevant and enduring is that it arose from a study where teachers *reconstructed* their understanding of what it means to be a science teacher in fundamental ways. In recent years there have been other innovations in science teaching that are also underpinned by substantial theoretical research, and we shall document some of these; however, results show that unless teachers really want to change, or really value how a particular change can make their and their students' experience more worthwhile, they will not alter how they perceive themselves as science teachers or radically change their practice.

In our view, Bell and Gilbert's model for teacher development continues to be powerful and relevant as it was underpinned by fundamental questions about teacher learning that we are still concerned with today, and which are appropriate to other innovations being implemented in science classrooms. Bell and Gilbert use the term teacher development interchangeably with teacher learning, yet a distinction between the terms 'development' and 'learning' has since received some attention in the literature. Garry Hoban (2002), for example, rejects the term development as conveying a mechanistic, linear view of learning, characterised by one-off workshops that tend to reinforce existing practice. Hoban argues for a paradigm based on complexity theory where teachers generate new ways to rethink and change existing practice within a professional learning system. Our view of teacher learning and how it can be facilitated coincides with Hoban's, as we show later; however, our interpretation of 'development' as used by Bell and Gilbert, encompasses the notion of ‘learning’, and their underpinning questions could be read as development or learning:

> What is the nature of teacher development?
> What factors help and hinder teacher development?
> What model of teacher development can be used to plan teacher development programmes and activities?
> What teacher development activities promote growth?
> (Bell and Gilbert 1996, pp. 9–10)

The following account in this section addresses the first three questions in terms of teacher learning, drawing on international perspectives and experiences from our own work in science education. The fourth question is addressed in a further section and focuses on specific examples from our experience of activities and contexts for learning within science education initiatives.

What Is the Nature of Teacher Learning?

The durability of the Bell and Gilbert model is also evidenced by its continued use in more recent attempts to theorise the nature of teacher learning and how professional practice can be changed in sustainable ways (e.g. Fraser et al. 2007). In drawing on the model, Christine Fraser and her colleagues make a distinction that we find useful between what is meant by ‘teacher learning’ and ‘professional development’:

> [T]eachers’ professional learning can be taken to represent the processes that, whether intuitive or deliberate, individual or social, result in specific changes in professional knowledge, skills, attitudes, beliefs or actions of teachers. Teachers’ professional development, on the other hand, is taken to refer to the broader changes that may take place over a longer period of time resulting in qualitative shifts in aspects of teachers’ professionalism. (pp. 156–157)

This distinction made by Fraser et al. has synergy with our interpretation of the work of Susan Loucks-Horsley et al. (2003), as these authors also refer to professional development in addressing broader issues of designing programmes, and to specific strategies for professional learning of teachers.

Besides clarifying their position on teacher learning and professional development, Fraser et al. incorporate the concept of teacher change, which they see as coming about through a process of learning that can be described in terms of transactions between teachers’ knowledge, experience and beliefs on the one hand, and their professional actions on the other. David Clarke and Hilary Hollingsworth (2002) also draw on both individual and professional aspects of learning in their account of ‘professional growth’; from a cognitive perspective, teacher growth involves construction of knowledge in the personal domain of the individual teacher, a perspective adopted in Shulman’s early work on pedagogical content knowledge (Shulman 1986), and from a situated perspective teacher growth is constituted through the evolving practices of the teacher (the professional domain). The need to conceptualise teacher learning from both perspectives is supported more widely in the literature; Hoban (2002) draws attention to the importance of both cognitive and situated perspectives in analysing teacher learning, by taking into account individual processes as well as social and contextual influences; Hilda Borko (2004), in taking what she terms a situative perspective, also emphasises the need to consider both individual teacher-learners and the social systems in which they are participants. The recognition of both cognitive and situated perspectives as important for understanding teacher learning in our view complements and builds on the work of Bell and Gilbert. We conceptualise teacher learning as a complex combination of the individual teacher's knowledge growth, the professional teacher practicing in a particular setting and the social teacher working collaboratively with others in that setting.

What Factors Help Teacher Learning?

In addition to a rationale for professional development based on perspectives of teacher learning is the need to consider how that learning takes place, for example, how the domains of Bell and Gilbert's model can progress, or how Clarke and Hollingsworth's 'growth' can be facilitated. Early studies undertaken by one of the authors enabled her to begin to identify the factors that can influence teacher learning. In the early 1990s, Shirley Simon undertook a study with Alister Jones, Paul Black and other colleagues called the Open-Ended Work in Science project, or OPENS (Jones et al. 1992). This project focused on how teachers, working alongside researchers, could make changes in their practice as they engaged in more inquiry-based activities in response to the new national curriculum in England. Working with a group of teachers we explored each existing situation to negotiate a starting point for development, planned the new approaches with the teachers who subsequently put these into practice, then reflected on and evaluated the changes and outcomes with the teachers. We found that teachers were so different in their individual needs and contexts that these features of existing practice, negotiation, reflection and evaluation were critical for change (Jones et al. 1992). Though the study was researcher dependent and did not follow through to gauge learning and sustained change, it alerted us to the need for establishing these features in a professional development context.

Some years later, Simon became involved in the professional development of teachers as part of a major innovation called Cognitive Acceleration in Science Education (CASE). CASE was founded by Michael Shayer and Philip Adey, drawing on a theoretical base derived from the work of Piaget and Vygotsky. Shayer and Adey set out to apply their analysis of students' reasoning in terms of Piaget's stages of development (Shayer and Adey 1981) and over many years established evidence for the effects of cognitive acceleration (Adey and Shayer 1994). They designed science curriculum materials to promote formal operational thinking (Adey et al. 1995), and a professional development programme to support teachers as they attempted to use the materials to promote cognitive conflict and social construction of reasoning. The development programme involved university-based workshops, in which teachers were introduced to the theoretical base, engaged in activities to experience cognitive conflict and construction, and shared with each other reflections on practice. These workshops were combined with in-school coaching (Joyce and Showers 1988), where ‘trainers’ observed lessons and gave individual or departmental feedback. Evaluation of professional development was not focused on individual teacher learning, but on sustained implementation by science departments. Collegiality and ownership of the innovation were seen as critical factors in helping to maintain its implementation, as evidenced in a study of ‘level of use’ conducted by Adey, Simon and others (Adey 2004). Factors influencing individual teacher learning became apparent through close contact with teachers, and included motivation to want to change, an understanding of the theoretical basis of the curriculum materials and teaching approach, and an appreciation of perceived benefits for students.

Our more recent work on research into professional development has drawn on the insights of Hoban (2002), who, in arguing for the notion of a professional learning system, identifies eight conditions that are needed to bring about teacher learning. These include:

- A conception of teaching as a dynamic relationship with students and with other teachers where there is uncertainty and ambiguity in changing teaching practice
- Room for reflection in order to understand the emerging patterns of change
- A sense of purpose that fosters the desire to change
- A community to share experiences
- Opportunities for action to test what works or does not work in classrooms
- Conceptual inputs to extend knowledge and experience
- Feedback from students in response to ideas being tried
- Sufficient time to adjust to the changes made

An evaluation of whether or not these conditions for learning are present in the context of an innovation can provide the basis for planning work with teachers. As Hoban points out, on its own, each condition is unlikely to sustain teacher learning; it is the combination of conditions that is important.

What Models of Teacher Learning Can Be Used?

In this section we look at ways in which factors and conditions for helping teacher learning have provided models for planning professional development. Models take different forms and we discuss some of the features of models that have informed our work with teachers.

Bell and Gilbert’s model (1996), which we have outlined above, included a key feature of progression in each of the three domains of development, personal, professional and social. The first stage of development occurs when teachers begin to see an aspect of their teaching as problematic (personal) and practicing in isolation as problematic (social), so they are motivated to seek out and try out new ideas in their practice (professional). As they progress in their development, teachers deal with feelings and concerns that come about as they behave differently, for example, loss of control, insecurity in subject knowledge, or uncertainty about how to intervene, and begin to change their ideas of what it means to be a science teacher (personal). They also begin to see the value of collaborative ways of working (social) and have confidence to develop their own ideas for classroom practice (professional). Progressing further in their development teachers feel empowered through increasing confidence (personal), they initiate or seek out collaboration (social) and eventually facilitate new kinds of professional development activities (professional). The notion of progression in this model can provide a basis for teachers to evaluate their learning within each domain, and how the three domains are intertwined. In an account of how particular teachers developed in the study, Bell and Gilbert identified the process of reflection as a key condition for progression. Reflection has become an integral part of many other models, either generating cycles of action, as in Jones et al.'s negotiated intervention (1992), or as a fundamental process for stimulating change, as in Clarke and Hollingsworth's Interconnected Model (2002).

Clarke and Hollingsworth built on Thomas Guskey's (1986) linear model for change and created a cyclic version with different entry points, where change is seen to occur through the mediating processes of reflection and enactment in distinct domains: the personal domain (teacher knowledge, beliefs and attitudes), the domain of practice (professional experimentation) and the domain of consequence (salient outcomes). In addition, the external domain provides sources of information, stimulus or support. The term enactment was chosen

> … to distinguish the translation of a belief or a pedagogical model into action from simply 'acting', on the grounds that acting occurs in the domain of practice, and each action represents the enactment of something a teacher knows, believes or has experienced. (p. 951)

The term 'reflection' originates from Dewey's notion of active, persistent and careful consideration where, for example, a reflection and re-evaluation of outcomes can lead to an alteration in beliefs and, hence, a reflective link between the domain of consequence and the personal domain. A further consideration of the Interconnected Model is the change environment, for example, being a member of a school community where colleagues can share the consequences of their experimentation. We have found this model particularly useful in mapping out changes we perceive over time in how teachers engage in an innovation. Teachers can be seen to be stimulated by external sources of ideas which prompt changes in practice (enactment leading to changes in the professional domain), they review their practice and re-evaluate what is important in their student outcomes (reflection leading to changes in the domain of consequence), begin to reconstruct their notion of teaching (the personal domain), which in turn leads to further enactment in the professional domain, a re-evaluation of outcomes and so on. Mapping progression using this cyclical model can form the basis of a dialogue between researchers and teachers, and amongst teachers, which enables them to recognise the continuous nature of their own learning and the processes through which it is mediated.

A useful analysis of different models is offered by Aileen Kennedy (2005), who presents a framework for looking at CPD (Continuing Professional Development) models in a comparative manner. The analysis focuses on the perceived purpose of each model, and Kennedy proposes a set of categories under which models of CPD might be grouped. These categories are organised along a spectrum that identifies the potential for transformative practice. The first set of models includes those that focus on training, such as the 1-day courses attended by teachers, usually off-site, deficit models that are underpinned by performance management, and cascade models where skills and knowledge acquired at training events are disseminated to colleagues. Kennedy identifies all of these models as being underpinned by transmissive views of teacher learning. These models can serve a purpose in terms of enabling teachers to become more informed, or broaden their knowledge and skills, but as they are essentially technicist in nature, they are unlikely to result in fundamental changes in pedagogy. The next set of models includes those based on coaching/mentoring and communities of practice, which Kennedy terms 'transitional' as they can support either transmissive or more transformative conceptions of teacher learning, depending on the nature of the relationships involved. Coaching could take the form of expert/novice partnerships or more collegial forms of peer coaching, whereas community of practice models would involve more than two people. Fundamental to successful CPD within a community of practice is the issue of power and the level of control over the agenda (Wenger 1998) exercised by the community. Models that can be transformative in bringing about sustained change would include those communities of practice where individual knowledge and experience is enhanced through collective endeavour. Shulman and Shulman (2004) provide models of learning communities that work through a shared vision or ideology that is realised through shared commitments supported by organisational opportunities for learning. Other transformative models include action research, where teachers analyse their own practice in order to make changes in a cycle of reflection and action, or include opportunities that provide links between theory and practice, reflection, construction of knowledge and autonomy involving a sense of empowerment. In our view, these models are most likely to bring about sustained change.

Practices for Teacher Learning and Professional Development

In designing professional development for science and mathematics teachers, Loucks-Horsley et al. (2003) identify six clusters of strategies for professional learning:

- The importance of aligning and implementing quality curriculum materials with opportunities to reflect on their use
- Collaborative structures
- Examining teaching and learning through action research and case discussion
- Immersion experiences where teachers benefit from engaging in activities designed for student learners

- Practicing teaching including coaching, mentoring and demonstration lessons
- Vehicles and mechanisms such as courses, workshops and strategies for 'developing professional developers'

In this section we draw on examples from our own practice of professional development to provide insights to the success of some of these and other strategies in setting up conditions for teacher learning and enhancing transformative aspects of professional development.

Curriculum Resources

The strategy of accessing good quality curriculum resources, embedding these within a scheme of work and having opportunities to reflect on their use was apparent in the CASE initiative. The materials produced by the CASE team (Adey et al. 1995) included detailed lesson plans for teachers that documented equipment needs, suggested timings and interaction strategies, and an abundance of student resources for each lesson. In the professional development programme, schools were encouraged to embed the 32 activities within the curriculum over a 2-year period, and to encourage all department members to adopt the scheme. Often this process worked well, as departmental implementation meant that all teachers could access the materials and were encouraged to teach the CASE lessons as part of an expectation to 'deliver' the programme for the school. However, many teachers had CASE foisted upon them without any sense of ownership, and much of the success of the innovation was determined by pioneering individuals who instigated the programme within their schools, convincing their senior management team of the CASE effects. When these individuals left the school to be promoted elsewhere, CASE often ceased to happen. However, the CASE approach of cognitive challenge and social construction became embedded within science teaching if it was valued, and it persisted either through the continued implementation of the CASE lessons themselves, or adaptations in different contexts that could be used to promote the same reasoning patterns.

Further experience of the power of good quality curriculum materials is evidenced in the argumentation projects undertaken by Simon since 1999. Simon worked with colleagues Jonathan Osborne and Sibel Erduran on a project called Enhancing the Quality of Argument in School Science (EQUASS). This project arose from concerns about extending the emphasis of school science to enhance reasoning (as with CASE), to help students develop their epistemological understanding (Driver et al. 1996), and to develop argumentation skills such as justifying claims using evidence in both scientific and socio-scientific contexts. The initial stage of this argumentation project involved a partnership with a group of teachers to design curriculum materials that would be aligned to their existing curriculum, thus addressing the requirements of the national curriculum. Individual teachers working on the project were provided with frameworks for argumentation activities (Osborne et al. 2004a) and either used them directly, adapted them, or designed new activities most suited to their school contexts and existing practice. Following the research phase that focused on teachers' changing practice (Simon et al. 2006), the team developed a set of resources comprising 15 lessons that included lessons aims, teaching procedures and student materials. This publication (Osborne et al. 2004b) formed part of a set of professional development activities called the IDEAS pack. The resources in the pack have proved invaluable in helping teachers new to argumentation to 'get started', in that the materials can be used as they are, or be adapted for use to match curriculum topics and classroom contexts. The resources have been the stimulus for the development of further activities by pre-service teachers (Simon and Maloney 2006) and practicing teachers engaged in a project of evidence-based professional development using portfolios (Simon and Johnson 2008). The IDEAS resources continue to provide a stimulus for ongoing work with teachers who are developing argumentation within whole departments in London schools; initial use of the actual materials has evolved to incorporate individual designs appropriate to curriculum needs and classroom contexts.

Recently, observations and conversations with teachers using IDEAS lessons have demonstrated the need to analyse more closely the design of the lessons and their implications for effective planning and teaching (Simon and Richardson 2009). The frameworks themselves, such as concept cartoons, competing theories or predict/observe/explain activities (Osborne et al. 2004b), do not provide a sufficient indication of how they will work in practice. The science contexts in which the lessons are set and the plan of how to put them into practice are critical factors, as are the teachers' interpretations, introductions within lessons and interactions with students. Presenting teachers with readily usable resources rests on an assumption that development comes from practicing specific processes. Our concern is with the question of *how* teachers construct activities from such resources that will enable students to develop their argumentation.

Immersion Activities

Immersion activities have become a feature of both CASE and argumentation professional development programmes. For example, in centre-based workshops of the CASE programme, teachers were provided with experiences to promote cognitive conflict, including student activities from the course materials. One example observed in CASE workshops included an activity where students had to blow into or tap tubes to make musical notes (Adey et al. 1995). The tubes varied in a number of ways; they were made of different materials and had different dimensions of width and length. Students were required to articulate their reasoning about which variables would make a difference to the pitch of the note, through designing combinations of tubes that would eliminate variables systematically. As teachers engaged in this activity they were encouraged to question each other about their reasoning, and enact the kinds of intervention that would stimulate conflict and social construction of reasoning with students. These immersion activities were a common feature of CASE workshops and helped teachers to discuss the essential features of the CASE teaching approach.

The IDEAS pack of argumentation lessons is accompanied by sessions designed to promote teachers' own rationale for argumentation, and pedagogic strategies for use in the classroom such as constructing arguments, group work, evaluating arguments, counter-argument and modelling argument. One immersion activity aims to help teachers consider that the evidential basis for scientific ideas is not easily articulated and, therefore, may not be explored in science teaching. Teachers are asked to decide what evidence there might be for some common ideas, for example, Day and Night are caused by a spinning Earth, plants take in carbon dioxide and give out oxygen during photosynthesis, living matter is made of cells, and we live at the bottom of a 'sea of air'. This activity helps teachers to think about the value of using argumentation activities to extend their teaching goals beyond a focus on content to include epistemic questioning about the evidential basis for scientific claims. Other immersion activities involve the use of group-work strategies, such as listening triads, to enable teachers to experience how such strategies might work with students. Triads are often used to explore the ideas within a concept cartoon (Naylor and Keogh 2000), where students express alternative ideas about a phenomenon, such as the rate of melting of a snowman with or without a coat. In the triad one participant takes on the role of explaining the ideas portrayed by the students in the cartoon, one takes on a questioning role and one a recording role. Immersion activities such as these, using the pedagogical strategies and IDEAS lesson plans together, not only enable teachers to think about their approach, but also provide a basis for them to analyse and become familiar with resources they can use with students.

Reflection and Sharing

We have seen that most models and perspectives of teacher learning include the notion of reflection. The idea of reflective practice became well established by Donald Schön (1983), who views the reflective practitioner as an expert performer capable of skilful action. Experienced practitioners acting in their everyday practice demonstrate the kind of knowledge, called 'knowing-in-action', that is tacit and which they depend on to work spontaneously. Schön sees knowing-in-action as the simplest component of reflective practice. In addition, 'reflection-in-action' is perceived as occurring during activity whilst the practitioner responds to the moment, resulting in constant adjustment to what is happening. A further component of reflective practice, 'reflection-on-action' involves thinking about an event after it has occurred. It is this component of reflective practice that is used in a general sense in the context of teacher learning. Many authors concerned with the nature of reflection have focused on different kinds of reflection on action, for example, Neville Hatton and David Smith (1995) and Lily Orland-Barak (2005) question what it means to be 'critically reflective'. Critical reflection can be contrasted to lay reflection (Furlong et al. 2000) or technical, descriptive and dialogic reflection (Hatton and Smith 1995). These levels of reflection are characterised by recounts of personal experience, whereas critical reflection reviews experience in the light of other forms of professional knowledge. Nona Lyons (1998) uses the metaphor of weaving and threading to illustrate how critical reflection can connect different experiences to bring into consciousness teachers' beliefs and values.

The role of reflection in the adoption of CASE, though clearly a feature of Adey's model (Adey 2004) and the CASE programme's intentions, was not structured into the work in schools outside of coaching by the developers, unless pioneered by the teachers themselves. In later cognitive acceleration programmes for younger children teachers were asked to write a log of their reflections, but few teachers found this useful (Adey 2004). Group reflections that took place between teachers who attended workshop days based at the teachers' centre were found to be more valuable. This model of building in reflective activity when teachers from different schools come together was adopted in all the argumentation projects undertaken since 1999. In the initial project, where individual teachers were implementing argumentation in isolation, reflection became an important component of centre-based days when they all met each other. Subsequent projects additionally involved teachers constructing written reflections in portfolios (Simon and Johnson 2008). The act of reflection was powerful, but the time for teachers to produce written reflections tended to be lost to other essential activities. The role of reflection has become more prominent as a mediating factor for teacher learning in ongoing research to develop argumentation practice in whole school science departments. Within each department teachers have embedded argumentation activities within the curriculum and meet once a month to reflect on their experience of teaching the activities. Over time the nature of shared reflection has changed from descriptive personal accounts of what went well or not, to more analytical observations of personal learning, effective practice and evaluation of student outcomes. Likewise in their analysis of teacher learning in communities of practice, Shulman and Shulman (2004) note the crucial role of shared meta-cognitive reflection, where teachers critically discuss their work with each other, and reflection is the central component of their model of teacher learning and development.

The act of reflection has great significance in the learning of pre-service teachers. For them the act of reflection is a prescribed process they have to demonstrate in their qualifying standards, and reflection on action is an important process for looking forwards when planning for the future. However pre-service teachers are limited in their ability to reflect meaningfully when they have little experience of theory and practice. The following account from Sandra Campbell's research on the process of reflection in pre-service teachers shows how the use of video can be a powerful strategy for enhancing reflective practice (Campbell 2008).

Video-Stimulated Discussions with Pre-Service Teachers

Pre-service teachers in England have to show evidence of reaching Qualified Teacher Status (QTS) by being assessed against standards produced by the Training and Development Agency for schools (TDA). A recent addition to these standards

(TDA 2007) requires pre-service teachers to 'reflect on and improve their practice and take responsibility for identifying and meeting their developing professional needs'. The standard presupposes that a teacher who is able to reflect on practice can learn from the knowledge and understanding gained from this reflective process, and can become a better teacher. But what is the nature of reflection for the inexperienced teacher?

The work of Chris Argyris and Donald Schön (1978) can be used to interpret and illustrate a pre-service teacher's reflections on practice. For Argyris and Schön learning involves the detection and correction of error. They suggested that when things go wrong, a starting point for many people is to look for another strategy that will address the problem while still working within their governing variables – these governing variables being their values that they are trying to keep within acceptable limits. In doing this they are not questioning goals and values, they are trying to find a way of working within the existing framework – what Argyris and Schön would term single-loop learning. An alternative response is to critically question the governing variables themselves, this they describe as double-loop learning. Such learning may then lead to an alteration in the governing variables and thus a shift in the way in which strategies and consequences are framed. The following scenario of a pre-service teacher learning how to teach practical science can be interpreted in this way. The teacher considered her first practical lesson as unsatisfactory because she had rushed the plenary session. On reflection she realised she had not given sufficient time earlier in the lesson for the students to carry out the practical work. In her subsequent lesson she laid out the practical equipment in a tray system to save time, which allowed more time at the end to consolidate learning. This new strategy became part of her repertoire, an example of single-loop learning. In a subsequent lesson, the teacher observed the students as they collected their equipment from trays and questioned whether this practice was limiting their autonomy and collective decision-making in practical work. She was now beginning to question the governing variables of her lessons and subsequently altered her strategies again, providing an example of double-loop learning where feedback from previous experience stimulates a questioning of assumptions previously taken at face value.

Pre-service teachers being asked to reflect on practice can thus be operating at different levels of criticality depending on their emergent professional knowledge. They are pressed to live up to the expectation that good teachers are reflective teachers (van Manen 1995), and yet they do not necessarily have adequate guidance as to how and when to reflect. Michael Eraut (1995) suggests that pre-service teachers may have neither the time nor the disposition to reflect because they need to develop habitual routines and become familiar with a wide range of situations; the imposition to reflect may be perceived as a threat. Reflection is difficult for novice teachers as their lack of experience limits their ability to meaningfully reflect during a lesson. Work undertaken with pre-service teachers suggests that if reflection on practice takes place in discussion with others, these teachers can find meaning where it was not initially obvious. In a study to explore ways in which pre-service teachers can be encouraged to reflect, Campbell (2008) conducted research into the use of video-stimulated recall of lessons, as video has been shown to provide a powerful means of stepping back and analysing practice when novice teachers engage in a dialogue about what is observed (Brophy 2004).

Working with three pre-service teachers studying for a Postgraduate Certification of Education (PGCE) at the Institute of Education, Campbell, who was their tutor, conducted video-stimulated recall (VSR) of in-depth interviews which took place in the week following her observation and filming of their lessons. A further interview was conducted a month later to ascertain whether the research had stimulated learning such that it impacted on practice. Campbell found that many initial comments were of a descriptive nature, for example, the pre-service teachers focused on how they were gesticulating with their hands whilst talking to the class, or how the students were behaving. Using Hatton and Smith's (1995) categories of reflective practice, she found that the most common kind of reflection was also descriptive. In some instances, the pre-service teachers reflected more deeply, stepping back from an immediate response to consider why they acted the way they had. Campbell calls this 'mulling reflection'. With some prompting and in discussion with their tutor two of the three pre-service teachers showed some instances of deeper, critical, reflection. As novices lacking experience this was not surprising. There was little unprompted discussion of subject pedagogy, with surface features such as the behaviour of the students tending to dominate the pre-service teachers' reflections. With prompting, more discussion of subject pedagogy took place, and guidance was needed to ensure that their reflection encompassed aspects of teaching and learning. The teachers in this small sample were aware of the drawbacks of having their lessons filmed, but did not believe that these drawbacks outweighed the benefits of the video. Through video-stimulated discussion they perceived advantages gained through talking about their lessons with a critical friend, and developed ideas for using the videos in a wider context.

Conclusion

In this chapter, we have drawn on international literature sources and our own experience in London to show how teacher learning can be conceptualised and professional development planned effectively. Teacher learning is a complex process, beginning with the pre-service teacher's experience and continuing throughout a teaching career. The motivation to learn comes from within a teacher as she or he reflects on the outcomes of practice, and perceives a need to change. Choices open to teachers who want to learn are often external courses they can attend, and though these can be beneficial and assist some aspects of learning, they are unlikely to initiate fundamental changes in how teachers view teaching and change practice. Increasingly, schools identify their own needs and initiate their in-house programmes of professional development, though change from within may be dictated from senior management rather than be part of a community of practice with a shared vision and commitment to change. Underpinning any approach to professional development is a perspective on teacher learning, and this perspective needs to be recognised and taken into account in the way in which the professional development is conceptualised. In a climate where teachers have to meet teaching standards and professional developers are subject to external demands that require particular models and content of professional development programmes, it can be a challenge to pay due consideration to the conditions, factors and mediating processes that promote learning. The analysis of teacher learning and professional development we have offered in this chapter shows the complexity of the task of those who, like the staff of Science Learning Centre London, have a role to play in making provision for professional development. Sharing our analysis of models of teacher learning and professional development that are based on clearly articulated views of learning helps to foreground the agenda of personal motivation, reflective analysis of practice and evaluation of salient outcomes that is at the heart of teacher learning.

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Chapter 23
Developing Teachers' Place-Based and Culture-Based Pedagogical Content Knowledge and Agency

Pauline W.U. Chinn

Introduction

An emerging area of research in science teacher education centers on the role of place and culture in supporting science teachers' development of pedagogical content knowledge (PCK), a transdisciplinary concept developed by Lee Shulman (1986). PCK focuses on the interaction of content knowledge with a teacher's ability to represent it comprehensibly to students. The US Science Education Standards (National Research Council 1996) implicitly expect teachers to apply PCK as they "select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students" (p. 30).

Susan Loucks-Horsley, Nancy Love, Katherine Stiles, Susan Mundry, and Peter Hewson (2003) wrote: "All educational changes of value require individuals to act in new ways (demonstrated by new skills, behaviors, or activities) and to think in new ways (beliefs, understanding, or ideas)" (p. 48). They encourage professional developers to "identify local needs based on analysis of student and other data" (p. 120) that incorporate "the community, policies, resources, culture, structure and history that surrounds it" (p. 265). Statements by policy makers and teacher educators recognize that science teachers are part of a social learning system in which teachers' competence can be assessed using two dimensions – knowledge of content; and knowledge of students' lives and communities.

Jean Lave and Etienne Wenger's (1991) view of learning as situated within communities of practice that are developing particular competencies, provides a rationale for developing teachers' PCK throughout their careers. The initial preparation

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of secondary science teachers guided by courses of study and shaped by content area accrediting bodies, lays the groundwork for the development of science content knowledge. Developing pedagogical knowledge as knowledge of the process of teaching is guided by courses of study that are shaped by educational and learning theories. Cheryl Mason (1999) structured three secondary education courses to be team-taught by a science teacher, a content area professor, and a science education professor to provide preservice teachers with a “thorough understanding of the interconnectedness of content knowledge, learning theory and instructional strategies” (p. 279). However, Margaret Niess and Janet Scholz (1999) found that preservice teachers with science degrees who completed a Masters of Arts in Teaching designed to develop PCK did not always “possess well-formed or highly integrated subject matter or pedagogy knowledge structures” (p. 265); this finding is consistent with reported research. Teresa Greenfield-Arambula’s (2005) review of multicultural science education literature suggested that secondary science teachers’ understandings of science as objective and impersonal tended to impede their recognition of the impact of sociocultural factors on teaching and learning.

The 2-year (or even shorter) span of many science teacher certification programs thus presents challenges to moving aspiring science teachers beyond newcomer status either in science content or pedagogical knowledge. But, once in a school, new teachers are expected to demonstrate growing competence in cross-scale, transdisciplinary learning systems that span content, classroom, school, and community. PCK develops through teachers’ ongoing engagement and experiential learning in communities of practice (COP) relevant to their work. Etienne Wenger (2003) considers these the “basic building blocks of a social system” as these enable participants to “define with each other what constitutes competence in a given context” (p. 80). Increasingly, effective professional development of in-service teachers is recognized as fundamental to school success and teacher satisfaction (*Education Week* 2004).

A view of PCK as dynamic and affected by changes in multiple social systems suggests three driving reasons for taking an explicitly culture-based and place-based approach to professional development in science. The first addresses the twin goals of scientific progress and broad-based scientific literacy (NRC 1996) and responds to international evidence of declines in students’ interest in science and technology (Foster 2005; Organization for Economic Cooperation and Development 2006). The second, equity and social justice, centers on well-known issues of underrepresentation of females, minorities, indigenous, and economically disadvantaged students in science, technology, engineering, and mathematics (Malcolm et al. 2005; Aikenhead 2006). The third, sustainability, is driven by growing concerns over sustainability of resources, global climate change, and ecosystem and human health.

Robert Kates and Thomas Parris (2003) published two papers in the *Proceedings of the National Academy of Science* that emphasized the place-based nature of sustainability science and the role of education in a societal transition to sustainability. In the first paper, entitled Long-term Trends and a Sustainability Transition, they argued for place-based approaches: “Because sustainable development takes place locally rather than globally, an important task for a place-based sustainability science is to identify the specific trends most relevant to such places and the ways in which local populations can contribute to altering the trends that affect them" (p. 8066). In the second paper, entitled Characterizing a Sustainability Transition, they emphasized the role of education, teachers, and literacy in enabling a global transition to sustainability. A recognized need for teachers with place-based science literacy aligns with studies that show that the most successful professional development enables teachers to "deepen and contextualize their subject-area knowledge … to respond to individual student needs" (*Education Week* 2004).

The next section of this chapter provides a definition and historical overview of place-based science education and ends with the challenges and opportunities presented by programs that exemplify communities of practice that are not neatly compartmentalized into school subjects or schedules. The following section reviews the literature on place-based teacher education programs, by focusing on issues of science literacy, equity, and sustainability, and ends with challenges and opportunities for developing place-based PCK and agency. The final section identifies implications for place-based and culture-based science teacher education in the twenty-first century and suggestions for further research.

An Overview of Place-Based Science Education

Historical Development: Western Perspectives

Articles on place-based science education began appearing a few decades ago, but transdisciplinary, place-based education has a much longer history under the labels of service learning, progressive, experiential, and environmental education. At the end of the nineteenth century, in response to what was perceived as narrow, formalized schooling separated from learners' lives, educators in Europe and the USA proposed a more holistic, child-centered, community-based approach to learning that became known as Progressive Education. American educational philosopher John Dewey (1897) observed in *My Pedagogic Creed* that a rapidly changing world made it impossible to prepare students precisely for their future lives. Dewey strongly favored active learning, viewed individuals as members of historical social groups, and emphasized education for a democratic society. He criticized school science for presenting science in ways that seemed new, foreign, and disconnected from learners' lives. Progressive science educators were guided by Dewey's (1958) vision of student-centered, experiential, inquiry-oriented learning: "In modern science, learning is finding out what nobody has previously known. It is a transaction in which nature is teacher, and in which the teacher comes to knowledge and truth only through the learning of the inquiring student" (p. 152).

In the final decades of the twentieth century, ideological differences between mainstream science education's anthropocentric, economics-oriented approach and place-based science's ecocentric, sustainability-oriented approach began to crystallize.

David Orr (2004) cited the influences of Bacon (union of knowledge and power), Galileo (superiority of analysis over emotion) and Descartes (separation of self and object) in shaping education systems in which political and economic forces favored individualism and consumption. Orr connected urbanization to loss of knowledge of place, values, and practices that societies need in order to live sustainably. In the context of global climate change and threats to ecosystems, he held that education must enable students to understand the impact of knowledge on real people and communities and "must now be measured against the standards of decency and survival" (p. 8) instead of against standards oriented to competitiveness in a global economy.

Chet Bowers (1999) argued that teachers who "are not introducing students to [an] ecological way of understanding relationships … are socializing students to the current reformulations of the Industrial Revolution agenda of using technology to exploit and control the environment" (p. 167). David Gruenewald (2008) noted: "What needs to be transformed, conserved, restored, or created in this place … [could] provide a local focus for socioecological inquiry and action that, because of interrelated cultural and ecological systems, is potentially global in reach" (p. 149).

International and Indigenous Perspectives

Masakata Ogawa (1995) proposed a multiscience view that recognized the contributions of indigenous knowledge across a range of cultures. Indigenous science educators, Olugbemiro Jegede and Peter Okebukola (1991) and June George (2001), focused on the central roles that authentic, place-based and culture-based learning could play in increasing underrepresented, indigenous, and marginalized students' interest. Gregory Cajete (1999) noted that "American Indians understood that an intimate relationship between themselves and their environment was the essence of their survival and identity as a people" (p. 4). Knowledge and competencies valued to the community developed through learning through shared observation, practice, and experience. Cajete (2000) emphasized the potential for indigenous practices, values, and long-term knowledge of place for informing Western science in participatory research oriented to sustainability.

Oscar Kawagley and Ray Barnhardt (1999) identified four indigenous views that could contribute to science knowledge and science education by countering the specialized, short-term perspectives of many Western scientific and educational endeavors. Indigenous views included: taking a "long-term perspective" to emphasize the cross-generational nature of education, recognizing that the "interconnectedness of all things" also applies to knowledge, valuing "adaptation to change" to emphasize the dynamic nature of education, and maintaining a "commitment to the commons" that recognizes "the whole is greater than the sum of its parts" (p. 134).

A human-in-ecosystem view is shared by international science educators and natural and social scientists engaged in the emerging field of sustainability science education. This approach recognizes interconnected social and natural systems as "complex adaptive systems where social and biophysical agents are interacting at multiple temporal and spatial scales" (Janssen and Ostrom 2006, p. 1465).

Reviews of Place-Based Programs: Characteristics, Outcomes, and Challenges

A review of US and Canadian outdoor, environmental, and place-based curricular programs by Janice Woodhouse and Clifford Knapp (2001) noted the recent emergence of place-based programs shaped by Dewey's emphasis on learning that is grounded in students' lives. They differentiated place-based learning from environmental learning, which is often classroom-based, and outdoor education that connects classroom learning to the natural or constructed environment. They noted that the goal of place-based educators "to prepare people to live and work to sustain the cultural and ecological integrity of the places they inhabit" (p. 33) situated purposeful learning in students' cultural and historical places. They found that place-based programs possessed five essential characteristics that establish the unique, local nature of each program: (1) natural and historico-cultural content specific to place; (2) multidisciplinary approaches; (3) experiential and/or service learning; (4) a broader focus than preparation for a technological and consumer-oriented society; and (5) understanding of place, self, and community as part of a social-ecological system. They concluded: "One of the most compelling reasons to adopt place-based education is to provide students with the knowledge and experiences needed to actively participate in the democratic process" (p. 33). Knapp's (2007) reflections on his own instruction showed that place-based learning communities supported coteaching and learning.

Since 2001, the Place-based Education Evaluation Collaborative (PEEC) has evaluated the effectiveness of six place-based program spanning 12 states and 100 rural, urban, and suburban schools. The challenge of assessing unique, localized programs to meet the interests of state and national policy makers and funders is revealed in the range of qualitative evaluation methods: interviews of 800 adult and 200 students, surveys of 750 educators and 2000 students, document review, and on-site observations. The PEEC report *Benefits of Place-based Education* (2007) identified outcomes of: improved student achievement, stewardship, and connection to place; development of school, parent, and community partnerships; engaged and enthusiastic teachers; and shifts in school culture toward collaboration and adoption of the ideals of place-based education. (Evaluation reports can be viewed at http://www.peecworks.org/PEEC/PEEC_Reports/.) These outcomes mirror Robert Sternberg's (2003) findings that teaching students to think analytically, creatively, and practically like experts performing real tasks led to a greater diversity of successful students, while conventional instruction reduced diversity and produced pseudo-experts unable to transfer learning to real situations.

Elaine Loveland's (2003) report on schools in the US northwest and Emeka Emekauwa's (2004a, b) evaluations of NSF-supported place-based science programs in Alaska and Louisiana reported similar outcomes of improved student achievement, development of school-community partnerships and positive changes in the culture of schools. But issues of assessment of indigenous students persist, particularly with respect to cultural validity, with researchers, theories, methodology, questions, and reporting needing to be appropriate to the population being studied.

Sharon Nelson-Barber and Elise Trumbull (2002) emphasized the need for "research on new approaches to assessment design and use that consider the role of culture in learning and assessment" including "studies within specific Native communities" (p. 142).

Programs for Developing Place-Based and Culture-Based PCK

Given the importance of incorporating local contexts, professional development programs increasingly focus on developing in-service teachers' expertise relevant to particular schools and communities. Where science teachers and students differ significantly in language, culture, and values, place-based programs incorporate an explicitly culture-based perspective in order to situate teachers' learning in meaningful contexts focused on underrepresented learners' knowledge and experiences. Ray Barnhardt (2002) noted positive outcomes from the University of Alaska's field-based program aimed at preparing teachers for rural Alaskan schools that serve high proportions of Native Alaskan and American-Indian students. Field-based faculty integrated formal education with indigenous skills and knowledge to help preservice teachers to develop culturally responsive instruction appropriate to their communities. The highest impact on student academic performance, parent attitudes, and community support was evident when Native teachers became a majority of the teaching staff.

A 20-year collaboration between the village of Minto and the University of Alaska Fairbanks has provided teachers with a week-long cultural immersion in the daily activities of Old Minto Cultural Camp guided by Athabascan Elders (Kawagely and Barnhardt 2007). Esther Ilutsik (2003) describes the translation of this university-developed, field-based professional development model into district-level initiatives that provide new and out-of-state teachers with site-based, elder-led cultural immersions.

Eric Riggs (2004) and Steven Semken's (2005) research on essential components of geoscience education for Native American communities addressed issues of underrepresentation. Riggs found that

> …persistent and successful Earth science education programs … include active collaboration between local indigenous communities and geoscientists from nearby universities [while] successful Earth science curricula for indigenous learners share an explicit emphasis on outdoor education, a place and problem-based structure, and the explicit inclusion of traditional indigenous knowledge in the instruction. (p. 296)

Semken's list of five essential elements of place-based geoscience education went beyond Rigg's focus on knowledge and praxis to include personal meanings in order to "promote and support ecologically and culturally sustainable living in that place," "integrate or at least acknowledge, the diverse meanings the place holds for the instructor, students, and community" and "enrich the sense of place of students and instructor" (p. 152).

Semken's interest in assessing place-based teaching in order to increase geoscience literacy and the diversity of geoscience students led to research with Semken and Freeman (2008) that involved utilizing surveys to measure changes in 31 culturally diverse undergraduates' sense of place in an experimental geoscience course based on his indigenous geology course at a Dine (Navajo) tribal college. Place-based pedagogy included three extra credit, optional 2-h inquiry field trips and indoor learning that was structured to be "as evocative of the natural and cultural landscapes of Arizona as possible" (p. 5) through the use of local mineral and soil samples, visuals, handouts, and stories of place. They found significant increases in students' place attachment and place meaning and concluded that these and other methods measuring changes in learners' affective and cognitive sense of place merit further study as "authentic assessment of place-based science teaching" (p. 13).

George Glasson, Jeffrey Frykholm, Ndalapa Mhango, and Absalom Phiri (2006) studied a culture and place-based teacher education program for Malawian educators that included visits to a nature preserve. They found that teachers welcomed indigenous science and inquiry-oriented pedagogies as a way to engage students and develop ownership of local environmental issues. When Lynn Bryan and Martha Allexsaht-Snider (2008) studied two rural, Mexican elementary teachers whose classrooms served as sites for teacher education, they found that these master teachers situated student learning in community experiences in order to mediate among school, science, and community knowledge and discourse. Their findings emphasize the importance of familiarizing teachers with the discourse patterns and life experiences of culturally different students.

Pauline Chinn's (2006) 3-year study of *Malama I Ka 'Aina*, a year-long, team-taught, place-based and culture-based science curriculum course, found that 60 in-service, predominantly nonindigenous teachers learned to connect Hawaiian and Western science practices and knowledge in their lesson plans and instruction. A community-based, 4-day immersion with nights spent at campsites and schools allowed teachers to learn from indigenous Hawaiians, scientists, instructors, and peers' exemplary programs and sites. Written evaluations revealed the transdisciplinary and transformative aspects of their learning. A Part-Hawaiian teacher wrote:

> It made tying Hawaiian culture into lessons more of a norm than an anomaly. It got me in touch with the types of teaching I was doing and made me want to do more life-relating lessons. I did more hands-on activities and related things more to how they will affect the students. I'm applying Hawaiian values and lessons to teaching all subjects—asking questions like 'how did the Hawaiians do this?' (p. 393)

Chinn's (2007) study of a place-based education workshop involving 19 experienced secondary science and mathematics teachers and administrators from eight Asian nations and the USA showed that, prior to a presentation on indigenous Hawaiian practices oriented to sustainability, most Asian participants viewed indigenous knowledge and practices as inappropriate for inclusion in science curriculum. Following the presentation and small-group discussions, their writings indicated a shift in their thinking and included critique of national curricula for excluding local issues and indigenous knowledge and for interfering with intergenerational transmission of knowledge. Videotapes of teacher-developed lessons showed that most connected students' prior knowledge, places, or cultures to science and mathematics content. Three years later, a biology teacher had quit her teaching position and entered a graduate program because:

> I have a dream to become a teacher trainer, sharing knowledge, and creating a local, needs-based curriculum for rural areas in Indonesia … we don't have curriculum to develop the student skills about how to hatch fish, how to plant algae, etc. … And believe me you have a contribution. … I saw you guys spend a lot of time, making a field trip to the Hawaiian village, [to] learn their wisdom. (p. 1261)

Chinn's (2008) study focused on five Native Hawaiian women of the 11 teachers who cotaught *Malama I Ka 'Aina* over a 3-year period. Unlike the other six nonnative Hawaiians (mostly male secondary science teachers), four were elementary teachers and none were science majors. While all 11 teachers developed programs that cared for school or clearly bounded restricted lands, only the women engaged in caring for public lands that were open to all. The women drew on knowledge of place and community to develop transdisciplinary communities of practice focused on monitoring and restoring common areas – beaches, bays, and state lands. Even after the grant, professional and social networks continued to sustain interactions, reciprocity, and the exchange of different perspectives.

Rebecca Monhardt and Jon Orris (2007) noted the importance of culturally knowledgeable instructors and pedagogy in their review of a place-based earth science program for teachers in schools with high proportions of American-Indian students. Though most teachers evaluated the program as personally empowering and providing science content and experiences relevant to their students, Navajo teachers were offended by some displays of museum artifacts and put off by Western pedagogical formats that they perceived as pitting participants against each other. They strongly recommended that instructional teams represent the cultures of participants in order to facilitate effective development of teachers' place-based and culture-based pedagogical content knowledge (PCB–PCK).

Overall, a review of the literature suggests that thoughtfully designed place-based and culture-based teacher education empowered teachers to contextualize lessons and to teach in ways that support diverse learners.

Implications for Place-Based and Culture-Based Teacher Education

Social and natural scientists are beginning to converge around a view of teaching and learning that is place-based, active, personally meaningful, and ethical. Psychologist Albert Bandura (2001) wrote: "Efficacy beliefs are the foundation of human agency. Unless people believe they can produce desired results and forestall detrimental ones by their actions, they have little incentive to act or to persevere in the face of difficulties" (p. 10). Psychologist Sternberg (2003) suggested: "We may wish to start teaching students to think wisely, not just well" (p. 5). In his 2002 AAAS Presidential Address, Peter Raven noted:

> The kinds of grassroots activities that are promoting sustainability on a local basis have become a powerful force throughout the world: perhaps they are, fundamentally, only a re-emphasis of what has been traditional. … The people who are pursuing sustainability in a direct and personal way will hugely affect the shape of the world in the future. (p. 957)

Kenneth Kaneshiro, Pauline Chinn, Kristin Duin et al. (2005) described three sustainability science projects in Hawaii, including Chinn's teacher education program that nested science learning communities within a cultural stewardship framework. They think that these learning communities provided microcosms of social-ecological systems in which to "develop the underlying theories and principles of 'sustainability science,' based on an understanding of the fundamental interactions between nature and humans" (p. 349). This suggests that place-based and culture-based science teacher education could help to address the overarching goal of science education – scientific literacy for all citizens – by preparing teachers to form transdisciplinary learning communities focused on issues of science, technology, and society that are relevant to healthy and sustainable social-ecological systems.

Reviews of published place-based science programs suggest that situating science professional development in the context of place-based issues is meaningful to teachers, their students and communities, and is supportive of teacher expertise and agency. However, few institutions of teacher education provided explicitly place-based and culture-based science education courses as part of their regular, ongoing programs. The fact that most programs were funded by private donors or government agencies suggests that there is a challenge in institutionalizing transdisciplinary, place-based science teacher education programs while colleges and universities continue to be compartmentalized and discipline-based.

This gap suggests that research on place-based and culture-based teacher education programs might focus on longer-term studies of teacher learning, expertise, and agency in order to capture changes in teachers' place and culture-based PCK, communities of practice, and student learning. As instructional time devoted to place-based science lessons tends to conflict with classroom learning oriented to high-stakes tests, research is also needed on the quality, depth, and breadth of student science learning. Research on effective teacher education and professional development programs might provide insight into teachers' learning across their professional careers and models amenable to institutionalization.

In conclusion, envisioning science teacher education as participation in place-based and culture-based communities of learners which address meaningful and relevant science issues holds promise of a path toward educational equity and transdisciplinary science literacy for all learners. A focus on real places and concerns empowers teachers as local experts and curriculum developers who are able to contextualize learning in students' communities, practices, and cultural knowledge.

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Chapter 24
Nature of Scientific Knowledge and Scientific Inquiry: Building Instructional Capacity Through Professional Development

Norman G. Lederman and Judith S. Lederman

Students' and teachers' conceptions of nature of scientific knowledge have been a concern since the early 1900s (Norman Lederman 2007). Similarly, students' abilities, and more recently their understandings of scientific inquiry, have been a concern within the science education community (National Research Council 1996). However, little research exists concerning the role of professional development in facilitating the desired change in students' and teachers' conceptions (i.e. how to help teachers to translate what they know into effective classroom practices). The existing literature reviews related to nature of science and scientific inquiry do not document the nature and impacts of sustained professional development in bringing about change. This chapter focuses on two large-scale professional development approaches (i.e. a localised teacher enhancement grant and a systemic change initiative) and a university-level programmatic effort in which our group has been involved in Chicago. Of particular importance are the relative impacts of these different approaches and the lessons learned that have impacted the nature of the professional development provided. Much debate permeates the literature on nature of science and scientific inquiry. Unfortunately, writers have not consistently considered the audience (i.e. K-12 students) of the desired instructional outcomes. In particular, it is important to consider the developmental appropriateness of stated instructional outcomes, empirical research related to students' and teachers' learning about inquiry and nature of science, as well the relevance of students' and teachers' understandings to the goal of scientific literacy. Consequently, using these criteria, it is important to clearly explicate our perspectives/views of the constructs of nature of science and scientific inquiry, as well the rationale for the importance of teachers' and students' understandings of nature of science and scientific inquiry.

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What Is Nature of Scientific Knowledge?

At this point, there could be some confusion about our use of the phrase 'nature of scientific knowledge' versus 'nature of science'. Originally (during the 1960s), the phrase 'nature of scientific knowledge' was used to describe instructional outcomes related to the characteristics of scientific knowledge (Lederman 1992) that were directly derived from the way in which scientists develop scientific knowledge (i.e. scientific inquiry). However, during the 1980s, 'scientific knowledge' was dropped from the original label of the construct and 'nature of science' was used to refer to the same idea. Unfortunately, this change of language might have led to the consistent conflating of nature of science and scientific inquiry (Lederman 2007). A clear delineation between the two constructs is provided below.

When one attempts to answer the question, 'What is science', it seems clear that one valid answer delineates science into a body of knowledge, process/method and nature of scientific knowledge. The body of knowledge refers to the various concepts, laws, theories and ideas that are well represented in our various science textbooks. The 'process/method' refers to what scientists do to develop/construct the body of knowledge. Finally, nature of science refers to the characteristics of scientific knowledge that are directly derived from the process/method used to develop the knowledge. Clearly, one can elaborate on the categories used to answer the original question, but few would validly disagree with the three-pronged answer provided here.

With all the support that Nature of Science (NOS) has in the science education community, it might be assumed that all concerned individuals have adequate understandings of NOS. Even though explicit statements about the meaning of NOS are provided in well-known reform documents (e.g. NRC 1996), the pages of refereed journals are filled with definitions that run contrary to the consensus reached in the National Science Education Standards (National Research Council 1996) and other reform documents. Some would argue that the situation is direct support for the idea that there is no agreement on the meaning of NOS (Alters 1997). More recently, Hipkins et al. (2005) have expressed concerns about the lack of consensus about NOS in New Zealand curricula. However, counter-arguments by Michael Smith (Scharmann and Smith 2001; Smith et al. 1997) suggest that more consensus exists than disagreement. Others (Lederman 1998) are quick to note that the disagreements about the definition or meaning of NOS that continue to exist among philosophers, historians and science educators are irrelevant to K-12 instruction. At the level of generality concerning NOS that is targeted for K-12 students, little disagreement exists among philosophers, historians and science educators. Among the characteristics of scientific knowledge corresponding to this level of generality are that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (involves personal background and biases and/or is theory-laden), necessarily involves human inference, imagination and creativity (involves the invention of explanations), and is socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between, scientific theories and laws.

What follows is a brief consideration of these characteristics of science and scientific knowledge related to what students should know. Although listings of the 'important' characteristics of NOS exist, the primary purpose here is to provide a frame of reference that helps to distinguish NOS from scientific inquiry and the resulting body of knowledge.

First, students should understand the crucial distinction between observation and inference. Observations are descriptive statements about natural phenomena that are 'directly' accessible to the senses (or extensions of the senses) and about which several observers can reach consensus with relative ease. Inferences are explanations about what is observed in the natural world, but are the result of human interpretation as opposed to being directly observed by the senses.

Second, there is a distinction between scientific laws and theories. Individuals often hold a simplistic and hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence. It follows from this notion that scientific laws have a higher status than scientific theories. Both notions, however, are inappropriate because, among other things, theories and laws are different kinds of knowledge that do not develop or become transformed into each other. Laws are *statements or descriptions of the relationships* among observable phenomena. Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is a case in point. Theories, by contrast, are *inferred explanations* for observable phenomena. So, kinetic molecular theory is the inferred explanation for what Boyle's law describes. It is important to note, however, that theories are as legitimate a product of science as laws. They are simply two different types of scientific knowledge and one does not evolve into the other.

Third, even though scientific knowledge is, at least partially, based on and/or derived from observations of the natural world (i.e. empirical), it nevertheless involves human imagination and creativity. Science, contrary to common belief, is not a totally rational and orderly activity. Science involves the *invention* of explanations and this requires a great deal of creativity by scientists.

Fourth, scientific knowledge is subjective. Scientists' theoretical commitments, beliefs, previous knowledge, training, experiences and expectations actually influence their work. All these background factors form a *mindset* that *affects* the problems that scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret, their observations. It is this individuality that accounts for the role of subjectivity in the development of scientific knowledge. Although objectivity might be a goal of science, subjectivity necessarily creeps into the development of scientific knowledge because humans do science.

Fifth, science as a human enterprise is practised in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows, affects and is affected by the various aspects of the culture in which it is embedded.

Sixth, it follows from the previous discussions that scientific knowledge is never absolute or certain. This knowledge, including 'facts', theories and laws, is tentative and subject to change. Scientific claims change as new evidence, made possible through advances in technology, is brought to bear on existing theories or laws, or as old evidence is reinterpreted from a different perspective.

What Is Scientific Inquiry?

Although closely related to science processes, Scientific Inquiry (SI) extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analysing data. Scientific inquiry includes the traditional science processes, but also refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge. From the perspective of the National Science Education Standards (National Research Council 1996), students are expected to be able to develop scientific questions and then design and conduct investigations that will yield the data necessary for arriving at conclusions for the stated questions. The Benchmarks for Science Literacy (American Association for the Advancement of Science 1993) are a bit less ambitious as they do not advocate that all students be able to design and conduct investigations in total. Rather, it is expected that all students at least are able to understand the rationale of an investigation and be able to critically analyse the claims made from the data collected. Scientific inquiry, in short, refers to the systematic approaches used by scientists in an effort to answer their questions of interest. Pre-college students, and the general public for that matter, believe in a distorted view of scientific inquiry that has resulted from schooling, the media and the format of most scientific reports. This distorted view is called 'the scientific method' (i.e. a fixed set of set and sequence of steps that all scientists follow when attempting to answer scientific questions). A more critical description would characterise 'the method' as an algorithm that students are expected to memorise, recite and follow as a recipe for success. The visions of reform, however, provide no single fixed set or sequence of steps that all scientific investigations follow. The contemporary view of SI advocated is that the questions guide the approach and the approaches vary widely within and across scientific disciplines and fields (e.g. descriptive, correlational and experimental).

The perception that a single scientific method exists owes much to the status of classical experimental design. Experimental designs very often conform to what is presented as 'the scientific method' and the examples of scientific investigations presented in science textbooks most often are experimental in nature. The problem, of course, is not that investigations consistent with 'the scientific method' do not exist. The problem is that experimental research is not representative of scientific investigations as a whole. Consequently, a very narrow and distorted view of scientific inquiry is promoted among our K-12 students.

Scientific inquiry has always been ambiguous within science education reforms. In particular, inquiry is perceived in three different ways. It can be viewed as a set of skills to be learned by students and combined in the performance of a scientific investigation.

It can also be viewed as a cognitive outcome that students are to achieve. In particular, the current visions of reform are very clear (at least in written words) in distinguishing between the performance of SI (i.e. what students will be able to do) and what students know about SI (i.e. what students should know). Unfortunately, the subtle difference in wording noted in the reforms (i.e. 'know' versus 'do') is often missed by everyone except the most careful reader. The third use of 'inquiry' in reform documents relates strictly to pedagogy and further muddies the water. In particular, current wisdom is that students best learn science through an inquiry-oriented teaching approach. It is believed that students best learn scientific concepts by doing science. In this sense, scientific inquiry is viewed as a teaching approach used to communicate scientific knowledge to students (or allow students to construct their own knowledge) as opposed to an educational outcome that students are expected to achieve. With respect to the projects reported here, the primary focus is on knowledge *about* SI, because it is this perspective of SI that is most often ignored in classrooms and in methods of assessments. Specifically, the following understandings about inquiry are most germane to the projects reported here:

1. Scientific investigations all begin with a question, but do not necessarily test a hypothesis.
2. There is no single set and sequence of steps followed in all scientific investigations (i.e. no single scientific method).
3. Inquiry procedures are guided by the question asked.
4. All scientists performing the same procedures might not get the same results.
5. Inquiry procedures can influence the results.
6. Research conclusions must be consistent with the data collected.
7. Scientific data are not the same as scientific evidence.
8. Explanations are developed from a combination of collected data and what is already known.

As with NOS, these understandings about SI are not considered to be definitive or comprehensive. Rather, these understandings are considered to be developmentally appropriate for secondary students and have been shown in empirical studies to be understandable by secondary students.

Why Teach Nature of Science and Scientific Inquiry?

The goal of scientific literacy has been a perennial goal of science education since the 1970s (American Association for the Advancement of Science 1993; National Research Council 1996; Douglas Roberts 2007). In general, the scientifically literate individual has a functional understanding of science concepts and can apply this knowledge to making decisions about personal and societal problems. Two aspects of scientific literacy are an understanding of NOS and an understanding of SI. In addition to the goal of scientific literacy, understanding these two constructs is also presumed to facilitate understanding of subject matter and increase one's valuing of science as a human endeavour. At this point, there is scant evidence that understanding SI and NOS actually provides the benefits to learners as advertised. However, the emphasis on these two constructs remains as strong as ever, perhaps even stronger. Unfortunately, developing teachers' understandings of NOS and SI is no easy task. It requires a long and continuous programme of professional development. In addition, just because teachers have an adequate understanding of SI and NOS, it is not necessarily the case that they will be able to successfully develop these same understandings in their students. This chapter describes three large-scale professional development projects in Chicago that have been successful in developing teachers' understandings of SI and NOS and enabled teachers to promote the same understandings in their students: (1) Project ICAN (Inquiry, Context and Nature of Science); (2) High School Transformation project (HST); and (3) a programmatic model.

Project ICAN (Inquiry, Context and Nature of Science)

ICAN was a 5-year teacher enhancement project funded by the National Science Foundation. The project ultimately involved 238 teachers in Chicago and 23,500 students. Although the focus of ICAN was on secondary teachers (6–12), there were 12 elementary teachers included in the project. Approximately 50 teachers were recruited each year for participation in ICAN. Engagement with the project involved one full calendar year. During each academic year, Project ICAN was comprised of four stages: Summer Orientation; Academic Year Activities; Summer Institute; and Science Internship.

Summer Orientation

Project ICAN began with a 3-day orientation. The main focus of the orientation was to introduce ICAN teachers to aspects of NOS and SI by engaging them in NOS and SI activities (National Academy of Science 1998), watching relevant videos, and reading NOS- and SI-specific articles. Reflective questions, debriefings and discussions followed these activities to enhance teachers' familiarity with aspects of NOS and SI.

An example of an NOS activity is the tube activity (National Academy of Science 1998). Teachers were shown a mystery tube and its behaviours. They were then asked to infer the internal structure of the tube and design and construct physical models that behaved in the same way as the original tube. The discussion focused on elements of NOS such as how and why inferences differed although observations were the same, how human subjectivity led to different models, and the inconclusive nature of scientific models. This was followed by authentic examples from natural science, such as models of the atom and the centre of the earth.

Academic Year Activities

After the orientation, 10 full-day, monthly workshops took place from September to June. These workshops were centred on further NOS and SI instruction in the context of science subject matter, curriculum revision and assessment. The NOS and SI activities were intended not only for enhancing teachers' understanding of NOS and SI, but also for improving their knowledge of how to teach NOS and SI. An explicit/reflective approach, as described by Fouad Abd-El-Khalick and Norman Lederman (2000) was emphasised.

To help teachers to understand the explicit/reflective approach to teaching NOS and SI, Project ICAN staff presented model lessons. In the mitosis laboratory activity described by Norman Lederman and Judith Lederman (2004), for example, teachers were provided with two different teaching approaches for the same activity. First, teachers were given a brief review of the different stages of mitosis and how to categorise stages from pictures, and then teachers were asked to count the number of onion root tip cells in each stage of mitosis within a given field of view under high power. After the counts were entered as data in a table, they used the relative frequencies of stages to calculate the relative time required for each stage. In the second approach, teachers were given the same brief review, but this time teachers were asked to answer how they decided when one stage ended and the other began and how scientists made the same determination. A striking difference was that the first approach involved teachers in doing an investigation, but without any integration of NOS or SI. Unlike the first approach, the second engaged teachers in NOS and SI discussions involving careful selection and placement of reflective questions, followed by attention to certain aspects of NOS, such as tentativeness, creativity, observation versus inference, subjectivity and empirical basis. Attention to understandings about scientific inquiry was also included, such as the recognition of multiple interpretations of the same data set and the limitations of data analysis. In addition, curriculum evaluation and revision in terms of the teaching of NOS and SI were also emphasised. Under our guidance, teachers brought their own curriculum materials, evaluated them, and revised some topics in order to teach NOS and SI.

Teachers were also encouraged to apply what they learned through ICAN workshops in their classroom, and to bring examples of classroom experiences (verbally or via videotape) to the following ICAN workshop to share and discuss with each other.

Summer Institute

After the academic year, a 10-day summer institute focused on additional examples of curriculum revision and instructional activities focusing on SI and NOS. In addition, a major emphasis was placed on the assessment of students' understandings. Several model lessons integrating NOS and SI were also provided by teachers from previous years of ICAN.

Science Research Internship

During the academic year, teachers also participated in a science research internship with a practising scientist on the Illinois Institute of Technology campus or in surrounding community resources (e.g. zoos, museums). The teachers' primary role was as participant observers. They observed the ongoing investigations in the research settings and discussed specific research content and techniques with the scientists. Teachers kept daily journals, guided by focus questions about connections between the research experiences and the aspects of NOS and SI as presented in the project. In essence, this experience served as a 'reality check' for the perspectives of NOS and scientific inquiry presented in project activities.

Microteaching

During the third year of ICAN, we found that many of the participants' NOS/SI lessons were still characterised by implicit instruction. For this reason, we decided to assign three microteaching lessons to teachers in order to improve their pedagogical skills related to NOS and SI. Microteaching refers to a peer teaching presentation that mimics what teachers plan to do with their students. During the last 2 years of the project, three peer teaching lessons were also required during monthly meetings. These lessons were planned and delivered by teams of teachers. A teacher team consisted of three to four members who were voluntarily changed for each peer teaching assignment. Each lesson lasted for 45 min and afterwards there was a brief discussion of the aspects of NOS and SI addressed as well as ways in which the lesson could be further improved. Additionally, we provided written feedback to all teacher groups in terms of how to better integrate NOS and SI with their lessons.

Data Sources and Analysis

Teachers' Understandings of NOS and SI

Data addressing changes in teachers' views were collected during the summer orientation and the academic year. The summer orientation activities were preceded by pre-tests of teachers' understandings using Norman Lederman's Views of Nature of Science (VNOS) (Norman Lederman et al. 2002) and Views of Scientific Inquiry (VOSI) (Lederman and Ko 2003) questionnaires. These questionnaires were administered twice during the academic year.

The NOS aspects assessed included the idea that science is tentative, subjective, based on empirical observation and a product of human creativity. The distinction between observation and inference was also stressed. Aspects of SI targeted by the

VOSI include (a) multiple methods and purposes of investigations, (b) multiple interpretations of data being possible, (c) distinctions between data and evidence, and (d) data analysis being directed by the questions of interest and involving the development of patterns and explanations that are logically consistent. Additional data sources included journal reflections and revised curricular materials. Development of teachers' views was sought by comparison of profiles for each participant generated from VNOS-D and VOSI responses.

Teachers' Understandings of How to Teach NOS and SI

Teachers were required to provide videotaped lessons and lesson plans to illustrate their attempts to teach SI and NOS to their students. The reader is reminded that, during the last 2 years of the project, peer teaching lessons were also required during monthly meetings. Observation notes of videotapes and for peer teaching lessons were analysed along with instructional plans.

Students' Understandings of NOS and SI

The VNOS is an open-ended questionnaire that assesses views of the various aspects of nature of scientific knowledge. The VOSI is an open-ended instrument that assesses various aspects of scientific inquiry.

The VNOS-D and VOSI were administered to students at the beginning and the end of the academic year. Additionally, ICAN teachers were asked to submit samples of students' work completed during the NOS/SI-focused lessons, as well as test items related to these same topics. These data provided evidence of the impact on ICAN on students' understandings.

Before analysing all data sets, a 5% sample from each data source was used to establish inter-rater agreement. Agreement levels of 80% or higher were reached in all cases.

Results of the Project

Teachers' Understandings of NOS

Overall, over 70% of the participants showed enhancement in their NOS conceptions. The majority held informed views about four or more target aspects. Most significant were the changes in their views of the tentative, empirical, inferential, creative and subjective aspects of NOS.

As compared with 19% prior to instruction, 64% teachers had informed views about the tentative aspect of NOS. Teachers commonly stressed how new technology and discoveries play a role in developing scientific knowledge. For the post-test, 75% of the teacher participants (vs. 36% for the pre-test) exhibited informed views of the empirical aspect of NOS. For example, one teacher stated that 'they [scientists] could find evidence that might cause a change in what was previously thought and found'. The distinction between observation and inference was the aspect of NOS for which most participants (i.e. 82% vs. 32% for the pre-test) explicated informed views at the end of the programme.

About 69% of teachers (vs. 20% for the pre-test) demonstrated informed views about the role of imagination and creativity. Initially, around 65% of teachers held a limited understanding of the creative and imaginative aspect of NOS in analysing and interpreting data, stating that 'scientists use creativity in planning only, but creativity in observation and analysing data is a kind of lying. That is not science'. During the project, such a view was replaced by the notion that scientists involve creativity and imaginations in all the scientific inquiry activities including data analysis and interpretations.

Approximately 74% of teachers (vs. 25% for the pre-test) exhibited informed views of the subjective aspect of NOS. Prior to instruction, most of the teachers believed that scientists reach different conclusions because they have different data. A typical comment was that 'science is subjective in that each scientist has access to different data and evidence'. These responses changed appreciably during the programme. For example, one teacher believed that scientists disagree about what caused the extinction of dinosaurs even though they all have the same information because 'different people make different inferences based on their life experiences, education and cultural surroundings'.

Teachers' Understandings of Scientific Inquiry

ICAN teachers generally showed a significant improvement of their understandings of SI. For example, 40% began the programme with the view that SI consists of a set of steps that should be followed to obtain the correct answer. It was believed that these procedures are followed by objective scientists. They viewed the process as controlled, with the scientist being objective. At the end of the programme, few kept such views (i.e. 3%). They demonstrated major changes in their traditional view of the scientific method: they recognised that there is no universal step-by-step scientific method. Further, they came to recognise multiple methods for conducting scientific investigations and that scientists can have different methods for reaching conclusions. Some of them still described investigations as having steps, but they did not view these steps as a necessary part of doing an investigation.

Teachers improved in their understanding of multiple or alternative interpretations for a given a set of data. Nearly 80% of teachers understood that scientists are able to arrive at different interpretations of the same data because of 'scientists' creativity, culture, and differences' and that scientists often come into the process with prior conceptions, past experiences, beliefs and values that affects how they look, view and interpret things. As one teacher put it, 'even if scientists are working together, subjectivity can play a strong role in formulating one's theory and influence how results are looked at'.

Teachers' Understandings of How to Teach NOS and SI

Analysis of microteaching lessons indicated that there was a continuum of pedagogical content knowledge for NOS and SI instruction, from an implicit to a didactic and to an explicit/reflective approach. In the first microteaching session, more than half of the groups demonstrated an implicit lesson in which students were exposed to hands-on activities, but without any attempts to teach NOS and/or SI. Consistent with prior research of Fouad Abd-El-Khalick et al. (1998), Richard Duschl and Emmett Wright (1989) and Julie Gess-Newsome and Norman Lederman (1993), teachers did not consider aspects of NOS and/or SI when planning for microteaching lessons. All lesson plans for those implicit lessons included target aspects of NOS and SI, but most of them did not incorporate how to address those aspects of NOS and SI. Indeed, aspects of NOS were infrequently specified as outcome in their instructional objectives. The objectives pertained to doing science and/or only to science content.

Data analysis indicated that the failure of teachers to use an explicit/reflective approach to teaching of NOS and SI was associated with teachers' assumption that students can learn NOS and SI by *doing science*. In thinking about how to teach NOS, teachers intuitively treated NOS and understandings about SI as doing science.

But, by the final lesson, no implicit teaching was found and about 25% of the lessons were characterised as didactic; 75% of the lessons followed an explicit/reflective approach. The common features detected in explicit/reflective lessons are that the ICAN teachers explicitly addressed target aspects of NOS in the introduction of a lesson and intentionally guided students to situations in which target aspects of NOS were embedded. The explicit and reflective comments and discussions were identified not only at the end of the lesson, but also while students were exposed to the NOS/SI-specific situations. Indeed, in all explicit/reflective lessons, assessment pieces were developed and enacted for monitoring students' understanding of NOS and SI. Teachers provided students with written questions, a quiz, or homework assignments including assessment questions.

Analysis of student work and videotaped lessons indicated many more explicit/reflective attempts to teach NOS/SI in years 4 and 5 of the project than in previous years. About 85% of student work included NOS/SI-related questions to help students reflect on target aspects of NOS/SI and to assess their understandings of NOS/SI in the context of science subject matter, while approximately 75% of videotaped lessons followed an explicit/reflective approach.

It seems to be evident that the three microteaching experiences provided the ICAN teachers in years 4 and 5 of the project with important opportunities to reflect on their understanding of NOS/SI to develop pedagogical knowledge. The ICAN teachers planned and presented their microteaching lessons three times and had the opportunity to observe and discuss 20 peer lessons. The microteaching experiences familiarised the ICAN teachers with teaching NOS/SI and helped them reflect and develop their pedagogical content knowledge related to NOS/SI.

Students' Understandings of NOS and SI

Changing teachers' views is necessary but not sufficient for changing students' views. Teacher intentions and pedagogical skills for integrating NOS and SI into classroom practices are critical. The analyses of students' data indicated increasing success in changing students' views with each year of the project. By years 4 and 5, over 60% of the students (vs. 15% for the pre-test) held adequate views on over 80% of the aspects of NOS and SI that were focused upon.

Pre-test data indicated that overall the students demonstrated naïve views of NOS and SI. The most significant changes in students' views were with respect to the inferential, empirical and subjective aspects of NOS. In terms of SI, 37% (vs. 3% for the pre-test) of the teachers' students came to understand there is no single scientific method', saying that 'they [scientists] follow more than one method. For example, one method is investigating (observing) what birds eat and the shape of their beaks and the other method is doing an experiment involving chemicals'. Students also advanced in their knowledge of multiple interpretations of a set of given data; 46% (vs. 10% for the pre-test) of the students feel that 'if different scientists perform the same experiment, they might not all come out with the same answer. All these scientists have a different way to view things. They might have the same data but a different way in interpreting it'.

Conclusions and Implications

The data analyses indicated that Project ICAN was successful in helping teachers to improve their pedagogical content knowledge related to NOS and SI. Teachers initially tended to adopt an implicit teaching approach in which explicit/reflective questioning and discussion about NOS and SI were not planned. In helping teachers to understand and implement explicit/reflective NOS and SI instruction, the results of this study suggest that there are two critical changes that need to occur. First, teachers need to realise that explicit instruction is better than implicit instruction. Even though several explicit activities and explanations for the difference between explicit and implicit NOS and SI instruction were given to teachers before, in the first microteaching session, 62% of groups adopted implicit instruction. The teachers initially believed that students could learn about NOS only by *doing science*. They confused doing something with knowing something (e.g. Fouad Abd-El-Khalick et al. 1998). Extensive experience is needed for them to realise that they are adopting an implicit approach, which is not generally effective for teaching NOS and SI and to understand that 'doing' something is not necessarily 'knowing' something.

Second, teachers need to be aware that a student-centred approach to explicit/reflective is better than a didactic approach. Most teachers realised their implicit teaching of NOS and SI after the first microteaching session. However, discerning this implicit approach was not sufficient for some teachers for implementing explicit/

reflective NOS and SI instruction. They intended to teach NOS and SI explicitly, but failed to address target aspects of NOS and SI in the explicit/reflective manner advocated by Project ICAN. A short and didactic discussion for NOS was assigned at the end of a lesson rather than a reflective and interactive conversation integrated into the flow of the lesson.

Over the 5 years of the project, peer teaching experiences appeared to be an important professional development experience. In years 4 and 5 of the project, peer teaching became more prominent and provided teachers with opportunities to reflect on their understanding of NOS and SI and pedagogical knowledge related to NOS and SI. ICAN teachers planned and presented their lessons three times and had the opportunity to observe and discuss 20 peer lessons. These opportunities allowed teachers to become more familiar with teaching NOS/SI and helped them to reflect and develop their pedagogical content knowledge related to NOS and SI.

The development of teachers' pedagogical skills related to NOS and SI in years 4 and 5 was consistent with the analyses of student work and videotaped lessons, which showed much more improvement for teachers in years 4 and 5. This result implies that teacher education programmes should provide teachers with opportunities to plan and implement explicit NOS and SI instruction and to observe and discuss peers' lessons. Teachers will more readily adopt what they see that their peers do rather than what is modelled by professional developers.

Developing students' understandings of NOS and SI is not simple. It takes an extended period of time to develop students' understandings, as well as teachers' understandings and relevant instructional skills. It is important to note that short-term professional development activities are likely to meet with less success. It is also important to note that short-term attention to NOS and SI with students, typically through an introductory unit, is also not likely to yield success. NOS and SI are themes that must be developed through extended professional development and integrated throughout science courses and grade levels when dealing with K-12 students.

High School Transformation Project (HST)

The High School Transformation Project is currently a 6-year project (in its third year) funded by the Bill and Melinda Gates Foundation and Chicago Public Schools. Different from Project ICAN, the HST is a high school systemic change effort. For the most part, participating teachers in ICAN are individual teachers from different schools. There are some clusters of teachers from the same school, but this is not the norm. HST eventually engages *all* science teachers in the science department of participating high schools. Although HST includes NOS and SI as unifying themes, there is an equal emphasis on subject matter knowledge. Finally, HST primarily focuses on student outcomes, while Project ICAN focused primarily on teachers. Nevertheless, HST involves extensive professional development for teachers related to NOS, SI and subject matter. It is important to note that the lessons learned from

Project ICAN related to the delivery of professional development and the teaching of NOS and SI significantly informed the structure of HST.

HST has just completed its third year and currently involves all of the biology, chemistry and physics teachers in 20 high schools. There are currently 164 participant teachers and 24,652 students involved in the project. Each year additional high schools are added to the project, with the ultimate goal of having approximately 50 high schools by 2012. Schools are active in the project for a period of 3 years. All 9th grade science teachers in identified schools are involved in year 1; year 2 involves both 9th and 10th grade teachers, and year 3 involves teachers spanning Grades 9–11.

HST consists of three essential elements that are repeated, with some modification, during each of the 3 years of each school's engagement. These phases consist of (1) initial professional development for participating teachers, (2) monthly academic year professional development workshops (divided between the university and an informal education site and (3) on-site academic year support from science coaches. A science coach was assigned to each school to work closely with each of the teachers on a daily basis. Support ranged from observing lessons and providing feedback, co-planning lessons, team teaching or actually modelling instruction for the teacher. In addition, the science coach helped to coordinate science instruction by meeting with the science department as a whole each week. Science teachers in participating schools had a common planning time to facilitate this coordination. Participating schools and teachers received all needed materials, revised and developed new curriculum materials for each course taught, and daily support from a highly qualified science coach. Coaches are either teachers on leave from their school district or PhD students in science education. During professional development workshops, teachers experience a wide variety of 'model' lessons, directly derived from the curriculum content, that exemplify the inquiry-oriented instructional model advocated. Again, the overall focus of instruction is 'traditional' subject matter, scientific inquiry and nature of science by using an inquiry-oriented instructional approach. The primary goals of this systemic initiative are to:

- Enhance high school students' science achievement
- Enhance high school students' understanding of and ability to do scientific inquiry
- Enhance high school students' understandings of nature of science
- Enhance in-service science teachers' understanding of and ability to do scientific inquiry
- Enhance in-service teachers' understandings about nature of science
- Enhance in-service science teachers' ability to teach inquiry, about inquiry, and nature of science
- Enhance in-service teachers' ability to use informal education sites to enhance instruction and student science achievement
- Develop leadership skills in participant teachers so that they subsequently can work with other teachers in their school districts.

The aspects of NOS addressed in this project are that scientific knowledge is tentative, subjective, empirically based, socially embedded, and dependent on human imagination and creativity. Two additional aspects involve the distinction between observation and inference and the distinction between theories and laws (National Research Council 1996). The aspect of SI that was of particular interest was knowledge *about* scientific inquiry, because this distinguishing aspect of current reforms has been the most difficult to realise in classrooms. Specifically, the aspects of SI that were of interest were that: all scientific investigations begin with a question, but do not necessarily test a hypothesis; there is no single set and sequence of steps followed in all scientific investigations; inquiry procedures are guided by the question asked; all scientists performing the same procedures might not get the same results; inquiry procedures can influence the results; research conclusions must be consistent with the data collected; scientific data are not the same as scientific evidence; and explanations are developed from a combination of collected data and what is already known (National Research Council 2000).

Data Sources

Achievement scores were derived from standardised instruments developed for the project by the American Institute for Research (AIR). These instruments went through strict content validation procedures using multiple groups of subject-matter experts and educators. A level of agreement of 80% or higher was achieved for each item on each of the resulting instruments. Kuder-Richardson (21) reliability estimates exceeded 0.80 for each subject-matter test (0.82 for biology, 0.86 for chemistry, 0.83 for physics). As for previously described ICAN project, we used the VNOS and VOSI to assess students' views of nature of science and scientific inquiry respectively.

Results of Project's First 3 Years

Science Achievement

During each of the first 3 years of the project, pre-test and post-test data were collected on students' achievement. For Biology, 3 years of data exist because it is focused on the first year of school engagement and then continued in the subsequent 2 years; 2 years of data exist for chemistry and only 1 year for physics, at this time. For each subject area, correlated *t*-tests ($\alpha = 0.05$) were used to verify that students exhibited significant gains in achievement. Because instruction was provided to intact classes, the number of classes was used as the unit of analysis for each statistical test. Significant improvement in test scores ($p < 0.05$) was exhibited in each of the 3 years for biology, each of the 2 years in chemistry, and for the 1 year in physics. Although it is expected that significant gains would be exhibited across a year of instruction, these students on average were achieving at relatively high levels by the end of the academic year. That is, biology achievement reached 75% for the first year, 76% for year 2 and 78% for year 3. For chemistry, the average achievement score was 84% for year 1 and 85% for year 2. The physics achievement level was 85%. It is important to note that, for the chemistry and biology scores, the different years represent different sets of students.

Understandings of Scientific Inquiry

Both students and teachers were pre- and post-tested on understandings of scientific inquiry during each year of the project. If a student or teacher was part of the project for 3 years, he/she was assessed on understandings for each of those years. In short, teachers and students were assessed each year in which they participated in the project. Chi-square analyses ($\alpha = 0.05$) indicated significant improvements in each aspect of scientific inquiry addressed. Within the group of teachers, the greatest gains were shown with respect to understandings that there is no single scientific method and that scientists viewing the same data could arrive at different interpretations. As expected, teachers assessed in multiple years showed consistent improvement from year to year. The largest changes in students' views were related to an understanding that there is no single scientific method and that all science investigations must begin with a question. As with subject-matter understandings, the final understandings exhibited by students and teachers are more impressive than the fact that significant changes occurred from pre-tests to post-tests. That is, the 'final' understandings noted here are not commonly observed in student and teacher populations.

Understandings of Nature of Science

Teachers and students were assessed with respect to their understandings of nature of science as they were with scientific inquiry. Chi-square analyses ($\alpha = 0.05$) were again used to identify any changes in understandings from pre-test to post-test. Significant changes were found for all aspects of nature of science assessed within the group of teachers. Students did not show any change with respect to their understanding that scientific knowledge is partly a function of human creativity and imagination. As with subject matter knowledge and understandings of scientific inquiry, the 'final' understandings are more important than the significant changes from pre-test to post-test.

Comparisons Across Years of Engagement

Because HST is a multiple-year systemic change effort (with unifying subject matter themes such as inquiry and nature of science), it was logically assumed that both teachers and students would become more proficient in knowledge and skills with additional years of engagement in the project (i.e. students in the project for 3 years would become more proficient in science than students participating in the project for only 1 year). With respect to teachers, it was assumed that they would become more proficient in both knowledge and teaching ability with increased years of involvement. Although students involved for more than 1 year were taking different subject-matter courses (e.g. biology, then chemistry, then physics) comparisons of subject-matter improvement across years indicated that students' achievement levels increased from year to year. That is, students in the project for 3 years tended to achieve at a higher level in their physics course than in their chemistry course, and higher in their chemistry course than in their biology course. Students participating for 2 years consistently showed a greater level of achievement in chemistry than in biology. However, these data should be viewed with caution because the achievement levels are being compared across different subject matters. Still, the trend of increasing achievement levels from biology to chemistry to physics runs counter to students' typical performance in these different areas of science. That is, students usually do better in biology than chemistry. As was noted earlier, students consistently showed improvement in their understandings of scientific inquiry and nature of science from year to year.

Analysis of co-variance (ANCOVA) was used to assess student performance in the same subject matter area for teachers who participated in the project for more than 1 year. For example, for biology teachers who participated in the project for 3 years, their students' performance in biology was compared across the 3 years. The same analyses were undertaken for teachers involved in the project for 2 years. The ANCOVA tests ($\alpha = 0.05$), using the class as the unit of statistical analysis, indicated significant differences across years, with student achievement increasing with each additional years of teachers' experience. For example, if a teacher had participated in the project for 3 years, his/her students performed best in the third year relative to the second year or first year of involvement.

Conclusions and Implications

HST is a multi-year systemic change initiative that focuses on improving students' science achievement on standardised tests and knowledge of NOS and scientific inquiry. The design of the instruction and professional development for NOS and SI were directly derived from our work on Project ICAN. The project has completed its third year and so far has involved a total 20 high schools with instruction in biology, chemistry and physics. Furthermore, the project has involved 164 teachers and 24,652 students. Teachers are provided with extensive on-site and off-site instructional support. To date, it appears that the project has been quite successful with respect to improvement in students' subject-matter achievement and knowledge about scientific inquiry and nature of science. Single-year or short-term professional development efforts are often criticised for their inability to promote systemic change (Loucks-Horsley et al. 1998). Because systemic change requires intensive, frequent and long-term interaction with schools, teachers and students, there is an accumulated effect over time. The results of HST support this contention. The longer that students or teachers were involved in the project, the greater were the gains in their knowledge (for students) and knowledge and teaching ability (for teachers). With respect to teachers, it seems that the longer that they are involved with the project the more proficient they become in successfully enacting instructional materials and activities. Anecdotal data collected from the science coaches corroborate this assertion. Students improved because they benefited from the accumulated knowledge and perspectives provided by curriculum themes, as well as from the change in academic culture in a school that was very focused on systemic change. However, there is also another possibility at play. The formative assessments used within each instructional unit were designed to model the kinds of questions that students would encounter on the standardised summative assessments. Hence, it is quite possible that the students became more comfortable, with time, about answering such questions. This is not the same as learning test-taking skills or a case of teachers teaching to the test. Rather, students often do not do well on high-stakes tests because of their inexperience with the question types and formats as opposed to lack of knowledge. This issue needs further investigation and will be tracked in future years of the project.

Linking Knowledge of Nature of Science and Scientific Inquiry to Classroom Practice: A Programmatic Model

The previously described large-scale systemic professional development efforts clearly benefitted from external financial support. In addition, each of the projects had the luxury of engagement with teachers over multiple years. However, within the semester-to-semester reality of university in-service programmes, long-term and intensive professional development is not possible. The impact that one hopes to have on teachers' knowledge and practices must occur within approximately 450 hours of class contact and, with respect to NOS and SI, the impact might be limited to the content of just several courses. Thus, the desire to have teachers' classroom practice sustain itself after finishing a degree programme is a much more serious concern than with a funded project lasting for as much as 6 years.

Although previous investigations have attempted to develop teachers' understandings of NOS and SI, and the ability to teach these constructs (Randy Bell et al. 2000; Renee Schwartz and Norman Lederman 2002), there has only been limited success in getting teachers to continue attending to NOS and SI in an explicit manner during instruction. Various reasons have been cited by teachers for their lack of follow-through (e.g. time constraints, curriculum constraints, perceptions of what students can learn). Nevertheless, science classrooms are still not characterised by any concerted instructional focus on SI or NOS. At the Illinois Institute of Technology, we have been experimenting with the sequence of two courses (i.e. a course focusing on NOS and SI and a course focusing on advanced teaching strategies) within our in-service Masters Degree programme. In this investigation, a course on NOS and SI was taught concurrently with a course on advanced teaching strategies in an attempt to track the relationship between the development of teachers' understandings of NOS and SI and how this development was related to their ability to teach NOS and SI in an explicit manner within the context of a science lesson. The aspects of NOS and SI addressed in this investigation were the same as those addressed in Project ICAN and the HST.

Programmatic Design

The sample for this investigation comprised the 15 high school science teachers (9 females, 6 males) who were part of a Masters Degree leadership cohort for secondary mathematics and science teachers. Seven teachers were biology teachers, three were chemistry, and two were physics. These teachers ranged in experience from 3 years to 28 years, with an average of 8 years. The teachers were simultaneously enrolled in a course on NOS/SI and a course in Advanced Teaching Strategies. The teachers had previously completed courses in curriculum, assessment and evaluation, clinical supervision and action research, and they were currently completing an action research study that they had designed during a previous course. The course on NOS/SI was a discussion-oriented seminar focused around the reading of various books and classroom activities designed to develop teachers' understandings of the various aspects of NOS and SI. The course assumed no prior knowledge for the teachers and the instructional approach consistently expected teachers to reflect on both readings and activities with respect to how science was characterised. Instead of the teachers being provided with a list to memorise, the aspects evolved from class discussions. This course was taught by one of the researchers.

The Advanced Teaching Strategies course provided teachers with reform-based model lessons and the chance to practice instructional models that focus on student thinking (three 40-min peer-teaching lessons). The particular models stressed were the General Inductive Model, Concept Attainment Model and Inquiry Model described by Paul Eggen and Donald Kauchak (2006). During each of the three peer-teaching lessons, teachers were expected to follow the instructional model stressed and to include attention to at least one aspect of NOS and one aspect of SI. Teachers were free to choose the subject-matter focus of the peer-teaching lessons. All lessons were videotaped and followed by a 10–15 min debriefing class discussion. Teachers were also expected to watch their own videotapes and write self-critiques of the lessons. This course was team taught by two additional researchers.

Data Sources and Analysis

Multiple data sources were used in this investigation. Data collected during the NOS/SI course included pre-test and post-test administrations of the VOSI survey and the VNOS survey. In addition, teachers' book reports related to books read and reaction papers related to short readings were analysed. A total of two book reports and five reaction papers constituted the data set from the course. The data collected during the Advanced Teaching Strategies course included videotapes of lessons, teachers' lesson plans for their lessons, and teachers' self-critiques. Again, pre-test and post-test administrations of the VNOS and VOSI were used to assess changes in teachers' knowledge during the NOS/SI course, while the reaction papers and book reports provided a measure of the development of teachers' knowledge during the course. The data from the Advanced Teaching Strategies course also allowed documentation of the development of teachers' knowledge of SI and NOS, but were primarily used to correlate teachers' instructional development relative to their growth in knowledge during the course. Finally, a random sample of five teachers was interviewed to ascertain what facilitated or compromised their ability to explicitly address NOS and SI in their lessons.

The VNOS and VOSI were independently scored by two of the researchers. For each aspect of NOS and SI, each teacher was rated as 0 (unclear), 1 (naïve), 2 (transitional/mixed) or 3 (informed). The level of agreement for the VNOS was 0.88 and 0.92 for the pre-test and post-test, respectively. Levels of agreement for the VOSI were 0.91 (pre-test) and 0.94 (post-test). All disagreements were discussed and a consensus score was reached for all teachers. Data from the book reports and reaction papers were individually scored by one of the researchers and a chronological profile was created for each teacher's development of NOS and SI knowledge during the semester. All three researchers analysed the relationship between responses to the pre-test and post-test surveys relative to changes noted in the reports and reaction papers. With no exceptions, the views expressed in the surveys mirrored what was noted in the reports and reaction papers, lending confidence to the validity of the assessment of teachers' understandings.

The lesson plans and peer-teaching lessons from the Advanced Teaching Strategies course were analysed with respect to explicit references to aspects of NOS and SI. The two researchers who team taught this course analysed the data. Only explicit references were noted because the emerging research has indicated that students views of NOS and SI are significantly impacted primarily through explicit instruction, not implicit instruction. Specific attention was paid to what aspects of NOS and SI were targeted by the teachers, how well these aspects were addressed explicitly, and how the teachers' instructional development was related to the chronological profile of their knowledge development.

Results

As mentioned before, teachers' views were categorised as unclear, naïve, transitional and informed for both NOS and SI. These categorisations were based on analyses of VNOS and VOSI surveys, as well as other artefacts from the Advanced Teaching Strategies course and NOS/SI course.

Nature of Science

Teachers showed significant changes (pre-test to post-test) on all aspects of NOS using chi-square tests *($p < 0.05$)*. The largest changes occurred with respect to the creative and subjective aspects of scientific knowledge, with the smallest changes occurring with respect to teacher's understandings of the cultural embededness of scientific knowledge and the relationship between theory and law. By the end of the NOS/SI course, 73% (11/15) of the teachers exhibited informed views of all aspects of NOS.

Scientific Inquiry

As with NOS, teachers showed significant improvement on all eight aspects of SI investigated (chi-square tests, $p < 0.05$). The largest changes occurred with respect to the ideas that all scientific investigations begin with a question, but do not necessarily test a hypothesis, that there is no single set and sequence of steps followed in all scientific investigations (i.e. no single scientific method) and that scientific data are not the same as scientific evidence. The smallest changes occurred for the ideas that all scientists performing the same procedures might not get the same results, that inquiry procedures can influence the results, and that research conclusions must be consistent with the data collected. Overall, 80% (12/15) of the teachers exhibited informed views for each of the eight aspects of SI.

A clear relationship between the development of teachers' understandings of SI and NOS was evident when data from the Advanced Teaching Strategies course and the NOS/SI course (i.e. teachers' knowledge profiles) were analysed. In particular, during the first peer teaching lesson, teachers tended to teach NOS and SI implicitly, as opposed to explicitly as intended in both the NOS/SI course and Advanced Teaching Strategies course. That is, the teachers demonstrated a strong ability to design lessons that engaged students in investigations of scientific phenomena, but there was virtually no explicit attention to the NOS and SI objectives included in their lesson plans. This tendency was related to teachers' relatively superficial (i.e. transitional) knowledge of the various aspects of NOS and SI. As lessons from the second and third peer teaching lessons were analysed, which corresponded to teachers' possessing more informed views of NOS and SI, it was clear that teachers became more proficient at explicitly addressing NOS and SI (during instruction) as the courses progressed. In addition, teachers tended to include in their lessons those aspects of NOS and SI for which they had the most well-developed knowledge. In general, it appeared that, for most aspects of NOS and SI, teachers became more proficient at teaching each aspect of NOS and SI as their knowledge became more well-developed. Interviews with randomly selected teachers also indicated that they also selected for teaching those aspects of NOS and SI that seemed to fit most seamlessly with the topic of instruction.

There were some trends, however, that did not fit with what was noted overall.

Although teachers showed large changes with respect to their understandings that all scientific knowledge involves some level of human creativity and human imagination, the way in which this knowledge was manifested in lessons was distorted in an interesting way. Initially, it appeared that teachers were teaching ‘creativity’ in an implicit manner. However, as the Advanced Teaching Strategies course proceeded, it became clear that teachers instructionally interpreted ‘creativity’ to mean that students should be allowed to use their creativity during an investigation. Again, teachers approached instruction in this manner even though they had demonstrated through their survey responses and other artefacts that they understood ‘creativity’ to mean that all scientific knowledge is partly composed of human creativity and imagination. The five randomly selected teachers who were interviewed explained their instructional approach by stating that students could not understand that creativity was involved in scientific knowledge unless they were allowed to be creative. Interestingly, the teachers did not have this difficulty in translating knowledge into instructional practice when it came to addressing subjectivity in scientific knowledge.

Conclusions and Implications

Research over the past 2 decades has made it clear that the most effective way to teach students about NOS and SI is through an explicit/reflective instructional approach (Abd-El-Khalick and Lederman 2000; Lederman 2007). Although numerous studies have shown success in enriching teachers’ knowledge about NOS and SI, teachers continue to struggle in their attempts to translate their knowledge into effective classroom instruction. This investigation attempted to enhance the relationship between teachers’ understandings and their instructional practice in the relatively short time span of a professional Masters Degree programme. The results indicated a strong relationship between the progression of teachers’ understandings and their instructional practice. On the one hand, this finding is intuitive because a teacher cannot be expected to teach what he/she does not know. But, the relationship is not a simple one because teaching practice does not immediately follow the development of knowledge of NOS/SI and knowledge of how to teach both. It was clear that the progressive development of classroom practice lagged behind the progressive development of knowledge.

Prior to this investigation, researchers have been content to study teachers’ and students’ conceptions of NOS and SI using an ‘input–output’ model in which the primary focus has been monitoring pre-test–post-test changes during a carefully designed intervention. With respect to research on teachers, this approach to research has left us with the knowledge that we can enhance teachers’ knowledge about NOS and SI, but with little knowledge of how teachers’ knowledge progressively moves from naïve views to views that are consistent with current reforms. Other research efforts have clearly indicated that, although teachers might possess the desired views of NOS and SI and knowledge of how to teach NOS and SI, this knowledge is not automatically and necessary translated into classroom practice (Lederman 1999, 2007). This investigation has provided insights into the relationship between the progression of teachers' knowledge about NOS and SI and the progression of their instructional abilities related to these two constructs. It is clear that teachers' knowledge precedes their instructional ability. Our findings here are consistent with what was noted in the previously described projects. The teachers in these projects were not immediately successful at teaching NOS and SI as soon as their knowledge of the constructs developed. It seems that having the courses offered concurrently is not as effective as having the courses run consecutively. In addition, the relationship between knowledge and action is much more complex than simply meaning that teachers must know what they are expected to teach. Rather, after teachers develop in-depth understandings of NOS and SI and knowledge of how to teach it, there is a period of 'negotiation' during which the teacher needs to carefully consider how and where to best integrate NOS and SI into the existing curriculum. Consequently, recommendations for the integration of NOS and SI throughout the curriculum should be carefully considered in the light of the subject matter at hand (which provides an important context) and teachers' knowledge and instructional approach. Thus far, researchers have not considered the interaction between subject matter and the ability, or willingness, of teachers to address NOS and SI.

Professional Development and Teachers' Knowledge of Nature of Science and Scientific Inquiry: Lessons Learned

The previously described projects varied widely in terms of scope and logistical format. Project ICAN and the HST project were two large-scale professional development efforts that involved hundreds of teachers and thousands of students in the Chicago Public Schools. The third project is actually the in-service programme at Illinois Institute of Technology. Although the projects differ, they all focus on helping teachers to develop their understandings of NOS and SI and then translating this knowledge into effective instructional approaches. Consequently, the various projects do have some commonalities. That is, the views of NOS and SI promoted are consistent and the instructional approach, within the professional development activities and the approaches that the teachers are expected to use with their students, are all based on the research-supported explicit, reflective teaching approach (Lederman 2007). With respect to the focus of this chapter on professional development, we have learned several lessons through our work.

In each of the aforementioned efforts, we found that professional development needs to be long term, frequent and intensive (Susan Loucks-Horsley et al. 1998). In particular, in the large projects, we found that it was critical to meet with teachers throughout the academic year on at least a monthly basis. In addition, Project ICAN and the HST both included 'up front' intensive (i.e. 2 weeks or more) work during the summer and intensive capstone experiences during the summer following the academic year. These professional development activities involved knowledge development first, followed by attention to the development of instructional approaches. Teaching teachers about NOS and SI concurrently with teaching them how to teach NOS and SI simply did not work well. The cognitive demand seemed to be too great. In the organisation of the in-service programmes at the Illinois Institute of Technology, we found that courses addressing NOS and SI are best situated sequentially as opposed to concurrently with courses on the teaching of NOS and SI.

Microteaching opportunities have been shown to be crucial for success in all three of our efforts, regardless of scope. That is, our teachers benefitted significantly from opportunities to teach NOS and SI to their peers, as well as observe their peers, followed by 'friendly' but productively critical feedback. In each of the long-term efforts, it was obvious that the effectiveness of microteaching opportunities increased as trust developed among the teachers and our staff. It is also important to note that, in our in-service programme, this trusting environment was also critical and it was just developed prior to the two critical courses discussed here.

In terms of the decades of research on teaching and learning NOS, and more recently on the learning of SI, the overwhelming majority has focused on descriptions of teachers' and students' knowledge and on the development of isolated instructional approaches for developing teachers' and students' knowledge. The only long-term efforts focused on the development of science curriculum, but such efforts have not met with much success. The work reported here leads us to believe that the nature of the professional development efforts is more critical than the particular instructional materials. In addition, it appears that the intensive and prolonged work with teachers in two of the three reported projects is also successful in generating teachers' enthusiasm for teaching NOS and SI. This enthusiasm is critical if teachers are to continue addressing NOS and SI in their classroom practice after the completion of grants and professional development efforts.

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Chapter 25
Mentoring in Support of Reform-Based Science Teaching

Thomas R. Koballa Jr. and Leslie U. Bradbury

As mentoring has grown in popularity as a means to support novice teachers, there has been an increase in the number of studies related to teacher mentoring. Early studies focused on the benefits of mentoring relationships, the needs of beginning teachers, and the possible roles that a mentor might adopt in a relationship with a new teacher (Gehrke and Kay 1984). More recent work has explored the content of conversations between mentors and novices and the impact that working with a mentor has on the classroom practice of the novice (Wang et al. 2008). While there is a great deal of research related to the topic of teacher mentoring, little of that is focused specifically on science teacher mentoring.

Consistent with teacher mentoring in general, the promise of science teacher mentoring has been associated with teacher retention and individual development, specifically directed at the satisfaction and practice of beginning science teachers (Coble et al. 2009; National Commission on Teaching in America's Future 2003). In this vein, mentoring has served as an important element of science teacher induction efforts (Luft 2003; Shore and Stokes 2006). Moreover, mentoring also has come to be viewed as a means of reforming science teaching (Koballa and Bradbury 2009). The ultimate target of this reform is the science learning experiences of students.

In this chapter, we review the research on science teacher mentoring. We first highlight the nature of mentoring and its influence on science teachers and their practice. Next, we discuss the professional learning that prepares mentors to support the work of science teachers and ways to position mentoring to facilitate science

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education reform. We conclude the chapter with suggestions for future research on science teacher mentoring that are likely to promote a culture of reform-based science teaching and learning.

Nature and Influence of Science Teacher Mentoring

Numerous studies have demonstrated the potential for mentoring to influence the practice of beginning teachers in positive ways (i.e. Evertson and Smithey 2000). Studies of science teacher mentoring at the elementary and secondary levels indicate similar influences, suggest alternatives to the traditional model of mentoring, and underscore challenges to the success of mentoring as a vehicle for teacher professional growth and for the reform of science teaching.

Elementary Science Teacher Mentoring

At the elementary level, the focus of research has been the amount and quality of mentoring offered to pre-service teachers during their internship experiences. In a survey-based study of 331 pre-service elementary teachers in Australia, Peter Hudson (2005) found that less than half of mentors modelled a science lesson, helped the intern plan a science lesson, or assisted with evaluating the interns' performance in teaching a science lesson. Similarly, in a study of 54 undergraduates completing a field-based elementary programme in a large urban area in the USA, 39% of interns reported that they did not see any science being taught and the majority of those who did observe a science lesson did so on an infrequent basis (Travers and Harris 2008). While these pre-service teachers did not observe their mentors engaging in science teaching, the majority felt that the mentors supported them in their own efforts at implementing science lessons.

Factors contributing to the dearth of mentoring for elementary science teachers are the lack of subject matter knowledge and science teaching experience of mentor teachers (Jarvis et al. 2001). In a study of two pairs of mentors and student teachers who observed science lessons taught by each other, conversations focused on general issues of classroom management and lack of subject-matter knowledge, though all participants reported learning from the experience (Nilsson and van Driel 2008). To help mitigate the problem of mentors who reported a lack of confidence in planning, managing and assessing science lessons, Tina Jarvis and colleagues (2001) developed science-specific checklists to support the work of the mentors. These checklists provided guidance for novices as they planned science lessons and for mentors when they evaluated novices' performance. Both mentors and novices reported that the checklists were valuable and improved the quality of science lessons.

Concerns have been raised that pre-service elementary teachers do not have opportunities to observe experienced teachers engaging in science teaching and that they are being guided by mentors who do not engage in science teaching themselves

(Travers and Harris 2008). These concerns have prompted calls for increased education for those who serve as science mentors at the elementary level. Hudson (2007) advocated the use of a survey instrument for determining the extent and quality of science mentoring in order to facilitate the planning and implementation of mentoring programmes that address the needs of elementary science mentors.

Secondary Science Teacher Mentoring

At the secondary level, more studies focus on science teacher mentoring as one component of induction programmes that provide a variety of mechanisms of support for beginning science teachers. In a study that compared beginning teachers engaged in four different types of induction programmes, only half of novice teachers who met with their assigned mentors felt that the meetings were useful (Luft 2009). These beginning teachers wanted more assistance with locating materials for laboratory activities and more ideas to encourage their learning about science teaching. Addressing novice teachers' needs for science-specific teaching materials, equipment and other resources was the focus of the Exploratorium Teacher Induction programme (Shore and Stokes 2006). Here, the construction of *Teaching Boxes* by beginning teachers and mentors served as a focal point for discourse about science content and uses of materials and equipment to engage students.

Several studies involved the needs and experiences of people who enter science teaching through non-traditional routes. One example is the New Science Teachers' Support Network, a university–school district partnership that supports science teachers who enter the classroom before obtaining their certification (Frazier et al. 2008). New teachers are provided with an instructional coach who is a retired science teacher, a school-based mentor located at the same school as the novice, and access to coursework, web resources and other professionals. The instructional coaches served a vital role during the novices' first 2 years in the classroom in improving in their abilities to establish laboratory routines, pace laboratory lessons and plan for efficient assessment and detailed lessons.

Other studies emphasised the influence of mentor–novice compatibility on the success of the mentoring experience. In a year-long study of two student teachers, Leslie Bradbury and Thomas Koballa (2008) found that differing conceptions of science teaching and mentoring brought to the partnerships by mentors and novices contributed to tensions within each pair that negatively impacted on the relationships and learning of the novices. In a unique application of a Myers-Briggs type inventory, Lucretia Tripp and Charles Eick (2008) found that secondary science student teacher placements were most successful when mentor and student teacher were matched based on personality constructs measured by the inventory. Compatibility was reflected in the pedagogical approaches used by dyads and the mentoring skills employed by mentor teachers. Mentoring vignettes have also been tested as tools for ascertaining mentor–novice compatibility. Test results revealed that vignettes are useful in uncovering science teachers' beliefs about mentoring that can contribute to both harmonious and discordant mentoring experiences (Koballa et al. 2008).

Alternative Forms of Science Teacher Mentoring

Mentoring traditionally has involved an experienced teacher in providing support and guidance to a novice teacher. In this apprenticeship model, the experienced teacher shares expertise related to topics such as managing student behaviour and planning meaningful lessons. As the popularity of mentoring grows, new models are beginning to emerge.

Eick (2002) described a case in which two novice teachers were assigned to one middle school classroom and shared the responsibility for planning and teaching classes. The two novices provided feedback and support to each other. When they experienced particularly challenging situations, they sought out more experienced teachers at their school. While the two realised that they were not able to enact their ideal vision of science teaching, they felt that they benefited from having each other as sounding boards. Similarly, three early-career secondary science teachers participated in peer mentoring by observing each other teaching through videotapes and Internet videoconferencing, and then met once a month with a science education staff member (Forbes 2004). These participants reported that their confidence in trying new instructional approaches increased as a result of the support that they received in this collaborative environment. In another study of science teacher mentoring nested in induction experiences in five different countries, 'facilitated peer support', in which novices gathered and shared their own problem-solving strategies with support from more-experienced personnel, provided an important source of learning (Britton and Raizen 2003).

Mentoring to Reform Science Teaching

Mentoring is considered to be a vehicle for improving science teaching by emphasising reform-based teaching practices in mentor–novice interactions. When viewed through this lens, reform documents such as *The National Science Education Standards* of the National Research Council (NRC 1996) provide guidance for interpreting the phrase 'reform-based science teaching'. These documents call for science to be taught in a manner that emphasises the nature of science and how new knowledge is developed by engaging students in activities that allow them to generate and answer questions (NRC 1996). Deep understanding of science concepts by all students and their application to real-life contexts are central goals. While facilitating learning experiences in their classrooms, teachers should consider the culturally based beliefs that students hold, safety considerations in managing laboratory experiences, and appropriate strategies for assessing student understanding (NRC 1996).

Research into the experiences of novice teachers indicates that, although they might enter the classroom with reform-based ideas about teaching, when they are supported by teachers who value more traditional notions of science teaching, the guidance that they receive serves to constrain innovation and shapes the new teacher to fit the norms valued at the school (Trumbull 1999). In an analysis of mentoring conversations between two science teacher mentors and novices completing an internship in their classrooms, topics that were discussed only briefly or not at all included the nature of science, inquiry, issues related to scientific literacy and science in the community, which are all central components in reform-based science teaching (Bradbury and Koballa 2007). Instead, the majority of conversations focused on general pedagogical knowledge. However, when novice teachers participate in mentoring experiences that are nested in induction programmes that focus specifically on science teaching with an emphasis on reform-based practices, they are more likely to include a greater number of extended inquiry lessons in their teaching repertoire than those who participate in general mentoring or induction programmes (Luft et al. 2003).

Access to reform-based mentoring was the impetus for the e-Mentoring for Student Success (e-MSS) project (Jaffe et al. 2006). Through the application of a mentoring curriculum that brings attention to reform-based instructional goals and students' science learning, beginning teachers received support and guidance from experienced science teachers and scientists via an online mentoring network. While not concerned about access, other mentoring efforts also employed online systems to focus mentoring discourse on reform-based science teaching. One such effort employed the Video Analysis Tool (VAT), which allows for the application of a range of 'lenses' through which teaching episodes can be systematically identified, captured, coded and analysed. Use of the VAT by secondary student teachers and their mentors revealed increased attention to reform-based practices in their mentoring conversations (Koballa et al. 2005).

Professional Learning for Science Teacher Mentors

Mentors of beginning science teachers are teacher educators. They are called on to work with novice teachers at different levels of knowledge and development, support novices as they enact reform-based teaching practices, provide logistical assistance and model exemplary knowledge of science content and pedagogy (National Science Teachers Association 2007). Thoughtful and well-designed professional learning opportunities are essential for enabling mentors to fulfill these obligations (Britton et al. 2000). Educational opportunities in which mentors participate influence their behaviour and the teaching practice of the novices with whom they work (e.g. Harrison et al. 2005).

Professional learning opportunities for science teacher mentors should be developed in partnerships between the schools where novices and mentors work and the university to ensure that the needs of all stakeholders are met (Dunne and Newton 2003). These learning opportunities should be available to both school-based and university-based mentors. Appropriate topics include: the needs of beginning science teachers (Adams and Krockover 1997); strategies for observing and promoting reflective conversations about novices' lessons (Koballa and Bradbury 2009); and conceptions of mentoring and science teaching that participants bring to the relationship (Koballa et al. 2008).

Mentors are likely also to benefit from learning experiences that address the fundamental tenets of reform-based science teaching and from assistance with planning and implementing instruction that reflects these tenets (Luft et al. 2003). This is a particularly important aspect of the professional learning of veteran science teachers who agree to serve as mentors, but who might not be well versed in the tenets of reform-based science teaching. Professional learning opportunities for these mentors could involve the in-depth exploration of standards documents along with preparing, testing and discussing model lessons and assessments.

As facilitators design professional learning opportunities for science teacher mentors, the needs of adult learners must be considered as well as the differences in understandings and expectations that school-based and university-based mentors might hold. Adults learn most effectively when they have a clear purpose for their learning and the learning is situated in real-life contexts (Mundry 2003). Time must be provided for school- and university-based mentors to articulate their understanding about learning, teaching and mentoring and to negotiate expectations for novice teacher performance. Examination of such documents as the National Science Teachers Association Standards for Science Teacher Preparation (2003) can serve to inform these negotiations.

Moreover, science teacher mentors need opportunities to work productively on in-depth investigations that build on their experiences and that provide adequate time for reflection (Loucks-Horsley et al. 2003). Providing opportunities for discussion and case writing allows mentors to apply their knowledge in classroom-based contexts (Koballa et al. 2010). The use of video clips offers another productive site for learning, as mentors could view clips of mentoring conferences that incorporate a variety of mentoring strategies and discuss the potential benefits and drawbacks of each in their own work (Brennan 2003).

One other important consideration in developing professional learning opportunities for science teacher mentors is that the programme enables sustained contact between mentors (Dunne and Newton 2003). As mentors engage with novice science teachers, they need a place to which to turn for ideas and support when difficult situations arise (Bradbury and Koballa 2008).

Positioning Mentoring in Science Education Reform

Because of their recent experiences with education coursework that emphasises reform-based science teaching practices, pre-service and beginning teachers are in a unique position to function as agents of reform (Davis et al. 2006). The mentoring support that they receive can play a pivotal role in determining whether novices enact desired reform-based teaching practices and help spread these practices in their schools (Luft 2009).

For this reason, careful consideration must be given to the criteria used for recruiting and assigning science teacher mentors. A frequently used strategy has been to choose mentors based on their seniority and reputation as classroom teachers (Wang and Odell 2002). However, it is important for persons responsible for assigning mentors to remember that science is composed of multiple disciplines, each with its unique content and associated ways of thinking and investigation. Thus, the preferred mentoring match for a beginning biology teacher is likely to be an experienced biology teacher rather than an experienced physics or chemistry teacher. This consideration should not overshadow the importance of choosing mentors who model and support reform-based science teaching.

In this vein, it is important that science teacher mentors are attuned to the culture of schools in which they work and its potential influence on the success of mentoring experiences (Feiman-Nemser 2006). It is possible that mentoring that supports reform-based science teaching could run counter to the traditional culture of science teaching present in a secondary school science department or among teams of elementary or middle school teachers. In contrast to what might occur in a traditional teaching culture, science mentors whose goal is to encourage reform probably will engage novices in conversations that could be uncomfortable at times, but which encourage careful reflection about reform-based practice.

Edward Britton (2009) makes the point that the needs of novice science teachers that can be addressed through mentoring can be viewed as a continuum that ranges from science-specific needs to general needs. This view is important for science teacher mentors to adopt as they reflect on the guidance that they give to novices about reform-based teaching practices. For instance, mentoring focused towards the science-specific end of the continuum that supports reform-based teaching practices might highlight for novices unifying concepts and processes of science, such as evidence, models and explanation (NRC 1996), that might not be at the forefront of their thinking when planning learning experiences for their students. It is equally important that mentors recognise that even the general needs of novice teachers, such as those associated with classroom management, have science-specific aspects that call for special guidance when viewed through the lens of reform-based teaching. For example, classroom discourse requires a different teacher stance when students are engaged in scientific argumentation than when they are asked only to respond to teacher questions.

Additionally, those involved in the development and enactment of mentoring programmes for novice science teachers should think about mentoring models other than pairing one novice with one mentor. Increasingly, it is becoming apparent that a team mentoring approach is required to meet the needs of novice teachers as they learn to teach in reform-minded ways (Britton and Raizen 2003). For instance, a team mentoring approach could be particularly beneficial for science teacher novices coping with teaching assignments outside of their primary content field. These teams might include school and university mentors who can provide different kinds of guidance and assistance.

Future Research on Science Teacher Mentoring

The needs of novice science teachers are many. Increasingly, these needs are intertwined with matters of reform-based teaching. More research is needed to better understand the needs of novice science teachers and the relationship between their needs and the demands of reform-based science teaching. Research that addresses the needs of novice science teachers could provide insight about the influence of science teacher preparation on their needs and how their needs change over time.

Given the increasing awareness of the usefulness of multiple mentors to support novice science teachers, more needs to be known about the factors that influence this complex web of interaction. Peer group mentoring and mentoring teams, for which individuals assume different responsibilities, warrant further exploration as possible alternatives to the traditional one-on-one mentoring model. There is a need for research into from whom and how novice teachers seek guidance that informs their practice. Investigations with this focus also might provide guidance regarding the potential of different technologies for putting novice teachers into contact with mentors who are not at their schools, such as was done in the e-MSS project.

An increasing number of researchers (e.g. Roehrig and Luft 2006) have noted the influence of school context and other contextual factors on mentoring relationships, yet little is known about the many contextual factors that can enhance or constrain mentoring in support of reform-based science teaching. The influence of the school principal on the success of science teacher mentoring is one aspect of school context that warrants investigation. More also needs to be known about the influence of such contextual factors as school level, novice's science subject specialisation, and out-of-discipline teaching on the success of science mentoring conversations and novice teachers' reflection and reform-based practice. With mentoring experiences often nested within induction efforts, there is also a need to determine the influence of other induction programme activities on the mentoring received by novice science teachers.

In order to engage novice science teachers in conversations about reform-based practice, the learning experiences for mentors of elementary and secondary science teachers must address the tenets of science education reform and highlight tools that will facilitate their efforts to examine instructional plans, observe lessons and provide feedback. University staff who serve as mentors for novice science teachers also could benefit from professional learning experiences. More needs to be known about the needs of teachers and university staff who serve as mentors and the kinds of learning experience that will prepare them to guide novice teachers of science at all grade levels to engage in reform-based practice.

In some schools, the efforts of mentors to promote reform-based science teaching will place them in the role of change agents. The role of change agent can be challenging for mentors, especially when their efforts to support reform-based science teaching run counter to the prevailing school culture. Functioning as an agent of change also can lead to situations in which a novice teacher rejects the mentor's advice. This rejection could arise because of uncertainty about the mentor's practices and motives. Research is needed that will inform the professional learning experiences for mentors who take on the role of change agents in schools and how to work successfully with novice science teachers who might not value mentoring that focuses on reform-based practice.

The Alternative Support for Induction Science Teachers (Luft and Patterson 2002) and Mentoring in Middle School Science (Education Development Center 2003) are two projects for which mentoring practice is solidly based on tenets of reform-based science teaching. Results from these two projects are very promising, indicating an influence of mentoring on novice teachers' understandings and practice that reflect tenets of reform-based science teaching. Even with these successes, more research is needed to document the impact of different reform-based mentoring efforts on teacher thinking and practice. In particular, more needs to be known about the influence of science teacher mentoring that is nested within general induction programmes.

Some policy decisions seem to suggest that mentoring influences students' learning through influencing teacher practice. However, the causal relationship between mentoring and student learning in science is less than clear (Koballa and Bradbury 2009). Research is needed to test this causal relationship and to determine if and how mentoring in support of reform-based science teaching affects student learning. In addition to science content knowledge, students' understandings of unifying concepts and principles, the nature of science and the applications of science to daily life could be included in investigations into this relationship.

Overall, the research reviewed in this chapter demonstrates the potential of mentoring for supporting the professional growth of novice science teachers. It also reveals that much is still unknown about mentoring in support of reform-based science teaching, but that there are many possible directions for future research that potentially could inform our understandings of this important arena of teacher learning.

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Chapter 26
Multi-paradigmatic Transformative Research as/for Teacher Education: An Integral Perspective

Peter Charles Taylor, Elisabeth (Lily) Taylor, and Bal Chandra Luitel

There's a crack in everything. That's how the light gets in.

Suddenly, or so it seems, we find ourselves in an age of great uncertainty; a new dark age, perhaps? The world is wracked by crises of unparalleled proportions, forcing us to rethink the fundamentals of our lives. Financial, climatic, health, resource and security crises are acting in concert to rob us with frightening speed of our confidence in the taken-as-natural primacy of our historic (Western) worldview. We are being forced to question our habituated ways of improving the material quality of our lives. Thanks to increasing public alarm it has dawned on us that for centuries our commitment to modernity, especially the seemingly unassailable drivers of science and technology, has fuelled unsustainable global exploitation. Prominent organisations such as UNESCO are lamenting the collapse of cultural, linguistic and biological diversity (Skutnabb-Kangas et al. 2003). The world's leading climatologists are warning that chronic pollution of planetary ecosystems, especially atmospheric carbon emissions, has created chronic damage to the planet's biosphere (Stern 2006). We are rapidly running out of time to curb our carbon footprint.

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Reflecting on how science education can contribute to resolving the problem of our survival on this planet we are inspired by Leonard Cohen's poetic notion in the epigram to this chapter, preferring to view this moment in human history optimistically as an unparalleled challenge and opportunity. We share Nobel Peace Prize nominee Ervin Laszlo's view that in order to avoid worldwide breakdown of social systems a macroshift is needed in the way we understand, respond to and reshape social reality. It is time to go beyond a narrow materialistic scientific view of reality and embrace a multidimensional world view of multiple interconnected realities in order to create 'a global civilization that possess[es] the will and the vision to achieve solidarity and translate it into international and intercultural coexistence and cooperation' (Laszlo 2008, p. 37). We understand that going beyond involves a transformation of consciousness to higher levels of awareness and understanding of self and other, and of the complex interconnectedness of all things. And so we advocate engaging science educators, especially those undertaking graduate research studies, in what Jack Mezirow (1991) calls 'transformative learning':

> … experiencing a deep, structural shift in the basic premises of thought, feelings, and actions. It is a shift of consciousness that dramatically and permanently alters our way of being in the world. Such a shift involves our understanding of ourselves and our self-locations; our relationships with other humans and with the natural world; our understanding of relations of power in interlocking structures of class, race, and gender; our body-awareness; our visions of alternative approaches to living; our sense of possibilities for social justice and peace and personal joy. (Morrell and O'Connor 2002, p. xvii)

How can graduate research students engage in transformative learning when to do so involves making their own (and others') subjectivities a key focus of their inquiries? Transformative research involves a process of examining critically our personal and professional values and beliefs, exploring how our life worlds have been governed (perhaps distorted) by largely invisible socio-cultural norms, appreciate our own complicity in enculturating uncritically our students into similar life worlds, creatively re-conceptualising our own professionalism, and committing to transform science education policy, curricula and/or pedagogical practices within our own institutions. How can research as transformative learning be represented in a doctoral dissertation and be legitimated as scholarly knowledge production?

Our purpose in this chapter is to address these questions. In doing so we draw on over 25 years of development in the field of qualitative social science research by pioneering scholars such as Norman Denzin, Yvonna Lincoln and Egon Guba whose scholarly work is well represented in the Sage *Handbook of Qualitative Research* (Denzin and Lincoln 2005) and the international journal, *Qualitative Inquiry* (http://qix.sagepub.com/). We start by considering the limitations of the traditional single-paradigm approach to educational research dominated throughout the twentieth century by hegemonic positivism and its derivative post-positivism. By the term 'paradigm' we mean a specific scholarly framework for conceptualising, investigating and communicating about the world; and, like Thomas Kuhn (1970), we recognise the incommensurability (but not incompatibility) of paradigms due to their contrasting ontologies (what is the nature of reality?), epistemologies (what type of justifiable knowledge can be generated?) and methods of investigation (how can we generate justifiable knowledge?).

We outline three research paradigms relatively new to science education – interpretivism, criticalism, postmodernism – and we consider the unique contribution that each is making to transformative research. In particular, we highlight the role of *new logics* for making new sense of personal experience of a complex and emerging world and *new genres* with which to investigate and communicate heartfelt concerns about the human condition. Drawing on recent graduate research in the field of cultural studies of science education we illustrate how multi-paradigmatic transformative research can be enacted. In closing, we adopt a perspective drawn from integral philosophy and generate a meta-theory about the compatibility of multiple research paradigms, justifying the transformative researcher drawing on all paradigms, including post-positivism.

Throughout the chapter we exemplify our arguments with reference to the nascent field of the cultural studies of science and mathematics education where graduate research students are exploring critically, reflectively and creatively their own cultural situatedness, excavating and re-honoring their indigenous cultural capital, generating authoritative voices with which to re-author their professional world views, and developing personal professional philosophies with which to generate seeds of liberation in the hearts and minds of their own students, many of whom are future teachers of science.

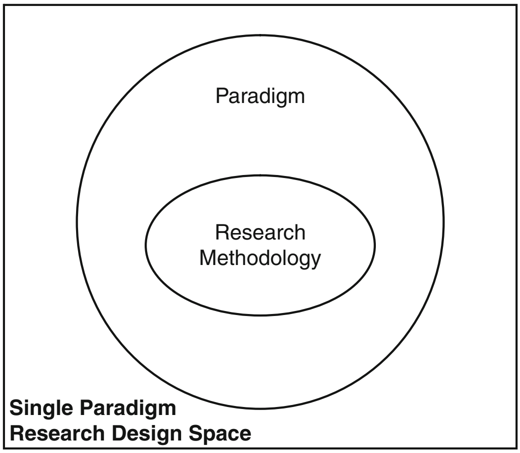
Single-Paradigm Research

Established for centuries as the standard-bearer of the scientific materialist world view, the positivist research paradigm has been, over the past 30 years, the subject of intense critique by philosophers of science and critical pedagogues (Kincheloe and Tobin 2009). Nevertheless, for historic reasons explained by Donald Schön (1983) and notwithstanding the rise in popularity of 'qualitative' research, positivism remains the dominant research paradigm in the social sciences, albeit in a 'softer' form called post-positivism. Jerry Willis (2007) gives an excellent account of all major research paradigms, describing post-positivism as directing a search for universal laws by employing an objectivist epistemology, a highly controlled, theory-testing methodology (or 'methodolatry'), and privileging academic research practice over the professional practices it purports to serve.

Our view of this research paradigm is mixed (Luitel et al. 2009). On the one hand, for reasons that we explain later in this chapter, we believe that it offers valuable methods for science education researchers. However, we are highly critical of its hegemonic stranglehold of graduate school research agendas inasmuch as it provides restrictive ways of thinking and writing that are not conducive to transformative learning.

The classical hypothetico-deductive logic of the post-positivist research paradigm comprises three powerful but restrictive logics, namely, propositional, deductive and analytical. Propositional logic entails reductionism that is exclusive of the ambivalence and uncertainties enshrined in our everyday realities, thereby ruthlessly reducing the notion of educational research to technical procedures. Whilst using deductive logic it is almost impossible to think outside of pre-existing laws and to deduce new truths. A narrowly conceived analytical logic promotes dualistic thinking, which can create unhelpful antagonisms between opposing attributes. Furthermore, positivism requires these logics to be expressed via the standard scientific genre of impersonal representation characterised by a neutral, passive, de-contextualised and distanced authorial voice. Although there is much to value in the standard logics and genre of the post-positivist paradigm, it is important to realise their limitations in accounting for and representing complex, non-linear, emergent and imaginative aspects of the thinking and actions of a transformative researcher.

Within a single-paradigm research design space framed by post-positivism the task of the graduate research student is relatively straightforward: to 'fill in the blanks' of a standard methodological template, ensuring that validity and reliability are the key regulators. In such restrictive scholarly conditions novice researchers, like the proverbial Chinese fish, may remain largely unaware of the epistemological 'water' in which they are immersed. Thus, when new research methods are encountered, especially in the absence of epistemological awareness, they are subordinated by the post-positivist paradigm under the seemingly inclusive label of 'mixed methods' research.



But our criticism is not directed at the single-paradigm model of research *per se*, rather we are concerned primarily with its restrictive nature, especially when it perpetuates uncritically and unimaginatively the prevailing tradition of post-positivism as the normative research paradigm. The problem is twofold. First, post-positivism privileges research that suppresses the subjectivity of the researcher, thereby failing to provide scholarly conditions for professional development as/for transformative learning, resulting in research serving largely to reproduce the prevailing research paradigm of post-positivism: an endless cycle of academia perpetuating its own existence. Second, the hegemony of post-positivism reproduces a narrow materialist scientific view of reality which reinforces the importance of learning uncritically a priori objective facts solely within a restrictive Western modern world view, to the exclusion of developing higher-order scientific literacy skills (Hodson 2008) with which to scrutinise the historical scope, philosophical boundary conditions and sociological limitations of this world view.

We believe that professional development of science teachers, especially via graduate research studies, should enable them to develop personally the transformative learning skills that they now are being called upon to develop in their own students, whether in school science or in college science teacher preparation courses. A pedagogy of transformative learning aims to raise students' critical awareness of the historic impact of science (and technology) on society, enabling them to develop ethical decision-making skills and a sense of personal agency for committing to make a difference, and fostering their empathic appreciation of alternative (ecological) knowledge systems embedded in other cultures (Settelmaier 2009). These transformative learning skills constitute essential components of the higher consciousness called for by Laszlo (2008) for combating the chronic crises threatening the planet's eco-cultural systems.

Multiple Research Paradigms

Critique of single-paradigm post-positivist research was precipitated by proponents of new research paradigms, two of which (interpretivism, criticalism) have become reasonably well-established in science education, whilst the third (postmodernism) is a relative newcomer still trying to establish a foothold.

Paradigm of Interpretivism

The interpretive research paradigm began to shape the thinking of science education researchers in the 1980s (Gallagher 1991). This paradigm is concerned primarily with generating context-based understanding of people's thoughts, beliefs, values and associated social actions. Its social constructivist epistemology foregrounds the researcher's unfolding subjectivity in shaping the process of the inquiry, especially the act of interpretation of the other's meaning perspective. Hallmarks of this paradigm are social constructivist standards of trustworthiness and authenticity (Guba and Lincoln 2005). Trustworthiness standards of credibility, dependability, confirmability and transferability are 'parallel to' the positivist standards of validity and reliability. Authenticity standards regulate the educative relationship between the researcher and his/her co-participants (or stakeholders) and include aspects of empowerment characteristic of the critical paradigm.

Interpretive researchers embrace an open-ended research design process that allows emergent research questions, emergent modes of inquiry and emergent reporting structure. The parallels with complexity scientists investigating emergent realities is quite striking (Horn 2008), leading us to speculate that interpretivist research might actually be scientific, in a post-Newtonian sense! The role of theory is quite different, no longer being entirely a priori, or situated at the front end of the inquiry. Theorising arises throughout the inquiry, the broader significance of which is supported by ongoing literature reviewing. Thus, the challenge for the research advisor is to find a way of resolving the perplexity of graduate research students indoctrinated into a post-positivist ideology as their entrenched objectivist epistemologies are challenged by this alien paradigm.

Culture studies of science education researchers employ interpretive research, especially ethnographic fieldwork methods, to understand the culturally situated nature of participants' beliefs and how they shape and are shaped by their normative social practices. For example, interpretive research has revealed how the everyday practices and communal artefacts of a Nepalese village community, living within a largely non-Western world view, have ethno-mathematics embodied informally and intuitively within them. This cultural knowledge was used to design mathematics curriculum materials for local schools to foster two-way border crossing between Nepali and Western world views (Kathmandu University 2008).

Paradigm of Criticalism

Science education researchers began to embrace the critical paradigm in the 1990s as a source of social values and transformative action (Kincheloe 2008). Central to this paradigm are concerns with social justice, bio-cultural diversity and sustainable ecosystems. Critical researchers employ ideology critique to understand how power imbalances serve as key sources of social injustice within normative social structures, especially how they give rise to and reproduce habituated behaviours of social groups (such as science curriculum writers, science teacher educators).

Critical researchers aspire to going beyond interpretive understanding of the social world to adopt an interventionst role and redress, for example, racial discrimination and climate change through advocacy and other forms of active engagement. One of these is a form of dialogical writing designed to engage the reader in reflecting critically on his or her own complicity in uncritically reproducing normative social values and practices; for educators, Max van Manen (1991) called this engaging the reader in pedagogical thoughtfulness.

Critical researchers strive to generate a professional praxis, that is, a practice aimed at social restructuring, at making a difference by, for example, working with socially and economically disadvantaged communities to foster their heightened social conscience, to develop their intellectual prowess, to enable them to envision a brighter future for their children, to empower them to unify around a heartfelt commitment, to project an articulate critical voice, and to hone strategic political skills in order to gain recognition and additional resources with which to transform their community and, ultimately, the broader society.

Critical science teacher-researchers use critical reflexivity (or critical self-reflective inquiry) as a self-study tool to help decolonise their own professional practices of hegemonic ideologies that serve asymmetric social interests; ideologies such as unabashed scientism and culturally de-contextualised (or 'pure') mathematics which, in industrially developing countries, can serve as vectors of neo-colonialism. Critical teacher-researchers aspire to help create emancipatory learning environments in which all students develop a critical conscience and civic mindedness. These advanced habits of mind enable students to engage in ethical decision-making about the impact on society of developments in science and technology, such as conflicting climate change policies, genetically modified food, human tissue transplantation, and euthanasia. Many graduates of emancipatory learning environments will become teachers of socially responsible science curricula.

Paradigm of Postmodernism

The postmodern paradigm is a recent arrival from the arts – critical literary studies, art and architecture, media studies – and has begun to exert an influence on science education researchers during the past decade (Taylor and Wallace 2007). Postmodernism elicits both fear and favour via its basic principle: 'be suspicious of all grand narratives' (including the 'grand narrative of postmodernism', respond its critics, not without irony). Forged in the fires of literary criticism, postmodernism (including post-structuralism, which metaphorically equates social life with text) has us constantly cocking an eyebrow, doubting the status of all universal knowledge claims – our own and others' – about the factual and moral truths of our empirical and ideational worlds, reminding us that every rational truth claim rests on a particular form of reason and is represented via a particular means of expression, none of which can rightfully claim primacy over others.

On the one hand, conservative science educators fear the 'slippery slopes' of a deconstructive postmodernism, which, by asserting a strong moral relativism, diminishes the long-established universalism of the Western modern world view. On the other hand, critical science educators, especially culture studies researchers, are embracing a constructive form of postmodernism with its central principle of pluralism. The power of constructive postmodernism lies in its opening the door into the multi-hued world of arts-based research (Eisner 2008), providing the transformative researcher access to powerful new logics with which to make new sense of and to act upon their personal experience of a complex and emerging world, and new genres with which to investigate and communicate their heartfelt concerns about the human condition (Luitel and Taylor 2007).

There are many new research logics; here we focus briefly on four. Firstly, dialectical logic allows the transformative researcher to hold contradictions together in creative tension so that, for example, *research as objective probing* (i.e. culture-free, disembodied) and *research as creative subjective envisioning* (i.e. culture-laden, embodied, emergent) can be given equal consideration without one denying the legitimacy of the other, just as the concept of light does not make sense without the concept of darkness (Luitel et al. 2009). In this chapter we signify a dialectical relationship by use of the '|' symbol.

Dialectical logic is often found in the company of metaphorical logic, which promotes open and embodied inquiry for exploring multiple facets of knowledge and knowing (Lakoff and Johnson 1999). Metaphorical logic enables the transformative researcher to engage in multi-schema envisioning, using elastic correspondence between conflicting schemas, in order to capture the complexity of a phenomenon. For example, an inquiry into transformative science teaching might explore the teacher's enactment of contrasting images such as *science as a body of knowledge*, *science as a process of inquiry* and *science as critical literacy* (Willison and Taylor 2006).

Narrative logic promotes thinking grounded in everyday life worlds (David 2006). Storied thinking enables transformative researchers to contextualise their knowledge claims within their personal, professional and cultural contexts (Clandinin and Connelly 1998). Narrative logic cultivates a diachronic vision, a means for conceiving the research process as a chronological evolution of emerging events, research foci and ideas. Diachronic vision helps make events intelligible in relation to what has transpired in the process of inquiry. Poetic logic enables the transformative researcher to experience non-real, envisioned and atypical reality, thereby reaching beyond the horizon of his/her conscious awareness towards the ineffable. Poetic logic can be useful for introducing non-linearity, silence, emergence, melody and meter, thus contributing to a holistic understanding of the world (Leggo 2004).

Amongst a plethora of new research genres we mention five. The first is narrative genres, which are used to speak from a lived, storied perspective bringing contexts, events and people to the textual space, thereby depicting richly the complexity of human experience. Many cultures bring forth storytelling traditions as a means of knowledge generation, depiction and transmission. Transformative researchers can use their natal cultures as a referent for structuring narratives to communicate research outcomes with their primary audience, articulating a dilemma, a moral tale, or a personal-professional story that paints a holistic sense of being and becoming (Cumming 2007).

Poetic genres help represent aesthetic-imaginative aspects of our knowledge claims through meter, rhythm, rhyme and playfulness (Christie 1979). Knowledge embedded in poetic genres evokes emotional, aesthetic, spiritual and interpretive responses. More so, a poetic genre is useful in transformative research to generate multiple, interactive and imaginative views of reality which help researchers to cultivate multi-perspectival envisioning of the issues under study (Glesne 1997). Within Eastern wisdom traditions there is a millennia-old truism that poetic eyes can reach further than the sun's rays.

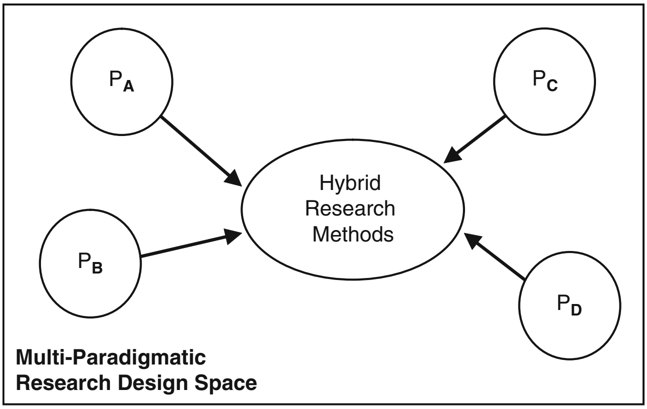
Performative genres such as plays or multi-voiced dialogue are designed to be acted out in professional contexts to stimulate transformative learning amongst an audience. A hallmark of performative research texts is that they are dialogic, embracing openness and uncertainties, thereby providing an interactive space for the audience. Transformative researchers construct performative texts in the form of ethno-dramas and ethno-theatre as means of generating resistance against repressive hegemonies (Saldaña 2005).

Non-linguistic genres – photographs, paintings, cartoons, collage, creative models – can represent knowledge claims otherwise unaccounted for by linguistic genres (Sullivan 2008). Transformative researchers use photographs and paintings to represent particulars, peculiarities and extraordinariness otherwise neglected in the mediative process of linguistic textuality. Cultivation of visual imagination can bring clarity to the articulation of knowledge claims, and can be achieved by juxtaposing linguistic and non-linguistic genres to foster pedagogical thoughtfulness in the reader/viewer (van Manen 1991).

Multi-paradigmatic Research

Thus, a new era of 'paradigmatic and methodological pluralism' (Paul and Marfo 2001) has emerged to create the necessary scholarly conditions for transformative research to flourish. Transformative research draws on the alternative research paradigms outlined above, particularly their new logics and genres, to conduct inquiries that are as much transformative of the researcher as they are of the participating other and of the social system in which self and other are embedded. Transformative research is a multi-paradigmatic approach as and for professional development of science educators: *as* a means of becoming change agents who wish to transform the policies, structures and processes of the teaching and learning of science, and *for* the purpose of ensuring that science (and technology) contribute to sustainable development, particularly of eco-cultural systems worldwide.

In the single-paradigm research design space considered earlier, post-positivism constitutes an ontological and epistemological framework within which students design their research methodologies. Methods of data collection (or data generation) introduced from beyond the borders of this framework are assimilated within this onto-epistemic space in accordance with the restrictive logics and genre of the post-positivist paradigm.



However, in the multi-paradigmatic research design space, it is essential to preserve the espistemic integrity of research methods drawn from various paradigms, and thus the pluralistic concept of referent (Tobin and Tippins 1993) replaces the restrictive concept of framework. The diagram represents a multi-paradigmatic research design space in which multiple paradigms (P_A, P_B, P_C…) serve as referential systems of knowledge production. The transformative researcher draws upon these paradigms, weaving together a hybridity of research methods with which to address complex research problems associated with the demands of their professional practice. Of primary importance is the need to ensure that appropriate standards of legitimation (i.e. quality standards or epistemic warrants) are used to regulate and justify different types of knowledge produced by the inquiry.

Culture studies researchers are currently working within multi-paradigmatic research design spaces, drawing on interpretive, critical and postmodern paradigms to create powerful hybrid research methods such as *critical auto|ethnographic inquiry*.

In critical auto|ethnographic inquiry, the autobiographical 'self' is set in dialectical tension against the ethnographic 'other', the researcher investigating critically his or her own cultural situatedness from the unique standpoint of both a cultural insider and border crosser, excavating the way in which his or her professional identity has been shaped (distorted) historically by hegemonic cultural, social, political and economic imperatives (Taylor and Settelmaier 2003). The autobiographical impulse directs excavation of the researcher's multiple life worlds by means of a variety of logics – metaphoric, dialectical, narrative – and seeks expression in a variety of genres – ethnodrama, poetry, imagery, dialogue, screenplay. Science and mathematics educators have reported successful critical and soulful auto|ethnographic studies of their own professional practices (Pereira et al. 2005).

In its many nuanced forms (evocative, soulful, critical), auto|ethnography has emerged as an exemplar of a hybrid research method for transformative research. Critical auto|ethnography enables culture studies researchers to explore their culturally embedded identities, to excavate and portray multi-hued accounts of their lived experiences, to generate critical reflexivity with which to deconstruct the hegemonic grip of their cultural history, to envisage with optimism, passion and commitment a culturally diverse and inclusive world, and to engage their readers in moments of pedagogical thoughtfulness.

Doctoral research completed by Mozambican science educators Emilia Afonso (2007) and Alberto Cupane (2008) combined post-colonial theorising and critical auto|ethnographic methods to develop professional philosophies of culturally inclusive teaching for Mozambique. As they examined their hybrid cultural identities (in colonial and post-colonial times) they generated auto|biographical memoirs, poems, stories, performance texts and images with which to explore and represent: (1) their lived experience as tribal indigenes who had since childhood crossed cultural borders into various hybrid spaces, especially the colonial space of Portuguese language and customs; (2) the mixed outcomes of their earlier professional struggles to render science education culturally diverse and inclusive; and (3) their vision as culture workers intent on transforming the professional practices of future generations of Mozambican school science teachers (Afonso and Taylor 2009). Thus, multi-paradigmatic research empowered Emilia and Cupane to transform their professional practices in accordance with a shared vision of creating culturally inclusive school science classroom environments wherein tribal children throughout

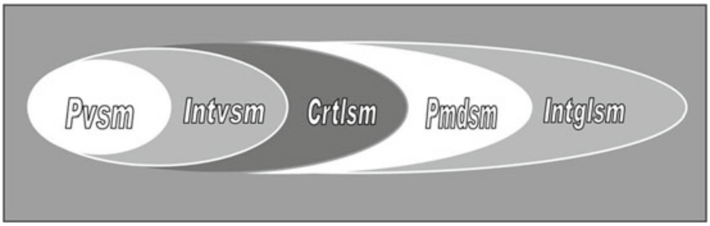
Mozambique can harness their cultural capital, especially their indigenous knowledge systems, and develop hybrid cultural identities with which to reconcile the tension involved in belonging simultaneously to pre-modern, modern and postmodern worlds.

An Integral Perspective

Thus far, our account of transformative educational research, which has drawn on multiple paradigms (interpretivist, criticalist, postmodernist) has all but excluded positive consideration of the positivist paradigm. In rejecting its hegemony and being critical of its restrictive methods, however, we do not intend to reject this paradigm because we recognise that it has great value for particular purposes. We turn to integral philosophy for an inclusive meta-theory of multi-paradigmatic educational research, utilising some of the new logics of the postmodern paradigm and its central principle of pluralism. In the process we propose an integral paradigm, which, we believe, is currently emerging from the postmodern paradigm, offering as yet largely unrealised ways of knowing for science educators to help address the global crises of the twenty-first century.

Integral philosophy – 'integral' meaning to integrate, to bring together, to join, to link, to embrace – can be regarded as a holistic philosophical referent characterised by the notion that it is not the individual mind that is celebrated but integral connectivity (Gergen and Gergen 2000). In the West, there is a common belief that if two opposites cannot be united, we try to either control or eliminate the oppositional pole of the bifurcation. An alternative strategy to this antagonistic Cartesian dualism is integration through dialectical logic: we attempt to transform both poles of a contradictory set of metaphors into a higher set of understandings where a higher level of synthesis is yet another departure point of further dialectic seeking (Slattery 1995). Integral philosophy uses dialectics to integrate dialectical systems by realising that all elements are interrelated and are reflections of an underlying unity. Applied to research, the dialectics of integralism allow for paradigmatic pluralism and for unity-in-diversity (Pallas 2001).

A key contribution of integral philosophy is that it helps us to understand the multiple research paradigms of the social sciences not as independent entities vying for legitimacy by pitting themselves against each other but as integral parts of a developing hierarchical system, each part (paradigm) building on its predecessor and giving rise to the next part (paradigm), and so on. What is distinctive about this system is the interdependence of the paradigms, best understood as the ongoing emergence of part–whole relationships in which each successive paradigm both transcends and includes its predecessor. It was the integral philosopher Ken Wilber (2000) who developed this theory of paradigm development. He drew on Arthur Koestler's (1976) view of naturally occurring hierarchies (called 'holarchies') in which each part (or 'holon') is itself whole and simultaneously a part of some other whole. The following diagram illustrates a holarchy of paradigms, with each paradigm emerging from (and including) earlier paradigms (from left to right) thereby creating a multi-paradigmatic system of knowledge production for social science research. This open-ended developmental process is driven by ongoing critical reflexive awareness of the inherent limitation of each paradigm to resolve significant social issues, leading temporarily to a state of chaos (a Kuhnian revolution) out of which emerges a more highly organised (or transformed) pattern of consciousness (i.e. a new paradigm) which can defuse earlier problems but which itself has inherent limitations, and so on.



The integral perspective, embodied in the integral paradigm, not only recognises the interconnectedness of multiple paradigms but also the 'moments of truth' in each of these distinctive knowledge production modes – each paradigm produces valuable knowledge – and accordingly it rejects attempts to privilege any single paradigmatic way of knowing. Thus, from an integral perspective, each way of knowing offers important but different and thus partial truths about the world, and all ways of knowing are equally legitimate and important. An integral perspective is not syncretism, where we would try to blend and homogenise differences into a whole. Pluralism respects differences residing across the variety of traditions without reconciling or integrating them. Unity-in-diversity and epistemological pluralism as proposed by an integral philosophy suggest that we have to learn to live with the ambiguity of difference which is a '…courageous practice, and engagement with the fact of diversity in our world' (Simmer-Brown 1994, p. 101). And is this not what Laszlo (2008) is calling for when he asks us to embrace a multidimensional world view of multiple interconnected realities in order to develop a synergistic global civilisation capable of cooperating to solve the planet's eco-cultural crises?

Cautionary Note

There is, however, a crucially important challenge for the transformative educational researcher who embraces the integral paradigm and attempts to integrate positivist research methods into the hybrid mix of methods drawn from other paradigms. History warns us that the long-established hegemony of the post-positivist paradigm lurks not out there somewhere (such as in research methods textbooks) but within the subconscious mind of most of us, for that is the legacy of our earlier science education, and that it will likely re-emerge to seize the methodology of the unwary researcher. Graduate research students are a primary target for post-positivism's subtle reassertion of its right to reify social reality and objectify understanding. Usually, the first sign is loss of authorial voice and sudden certainty about foretelling the long-term outcome of the inquiry. The antidote is for the transformative researcher to keep in touch with all of the epistemologies underpinning the inquiry (perhaps making wall charts of them). Criticalism will alert us to maintain a critical reflexive awareness of the power and scope of post-positivism's epistemological ideology, and to keep monitoring whose political interests are being served by the unfolding inquiry. Interpretivism will alert us to ensure that there is plenty of room for emergence of new research questions, new methods and new theorising, especially progressive development of our own subjectivity, and to keep making the familiar strange. But it is not only data collection and analysis methods of post-positivism that are a problem in this regard, its hypothetico-deductive logic and impersonal genre are especially worrying because they exert a subtly powerfully hold on our thinking. And thus we need also to remain mindful of the type of logic we are employing and to consciously allow plenty of space for exercising alternative logics and for allowing the constant process of writing narratively (and poetically, etc.) to actually constitute our unfolding inquiry (Richardson 2000). And once we have established these important habits of mind we can safely and profitably make use of the unique research tools that post-positivism has to offer. In this way incommensurable paradigms can become compatible and coexist peacefully (Watkins 1970).

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Chapter 27
Teaching While Still Learning to Teach: Beginning Science Teachers' Views, Experiences, and Classroom Practices

Julie A. Bianchini

Sharon Feiman-Nemser (2001) described learning to teach as a lifelong process – as a continuum stretching from preservice teacher education, through induction, to participation in professional teacher communities. Beginning teachers, she continued, find themselves in the unique and difficult position of teaching while still learning to teach. Further, Julie Luft (2007) argued "that the induction years encompass a vital phase of science teacher development…. Beginning teachers are different from their preservice and in-service counterparts and deserve some undivided attention" by researchers and professional developers (p. 532). In response to these kinds of descriptions of teacher learning, science education researchers have begun to conduct more studies of beginning teachers so as to better understand the substance and structure of these initial years in the profession. The purpose of this chapter is to highlight what we have learned about the views, experiences, and classroom practices of beginning science teachers and to identify what avenues are in need of further investigation.

To begin, it is important to note that science education researchers do not share a singular definition of beginning, new, or early-career science teachers. I defined science teachers in their induction years – or beginning science teachers – as those employed during their first 3 years in the profession. I included those enrolled in internship or alternative certification programs if teaching full-time or part-time. I also included beginning elementary teachers – both generalists and science education specialists – when the subject matter under discussion was science. This definition of beginning science teachers differs in a number of ways from that offered by Elizabeth Davis et al. (2006): They included as new both preservice and early-career teachers, and defined early-career teachers as those in their first 5, rather than 3, years of practice.

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What Do We Know About Beginning Science Teachers?

Because the last *International Handbook of Science Education* was published in 1998, research discussed here spans 1998 to 2010. A pervasive theme across these more recent studies of beginning science teachers is that learning to teach is a complex and demanding task. Challenges beginning science teachers face range from interrogating their own deeply held beliefs about teaching and learning, to filling gaps in their knowledge of students, science content, and instructional strategies, to overcoming inadequate support and resources in the schools in which they work. As a result of these and other challenges, Richard Ingersoll (2003) found that 29% of beginning teachers in the USA, including those in science, leave the profession after only 3 years. Although US science and mathematics teachers do not leave their jobs at higher rates than teachers in other disciplines, they are more likely to cite job dissatisfaction as their reason for leaving.

Research Bridging Teacher Education and Classroom Practice

Research on beginning science teachers is thought necessary both to improve the education of preservice teachers and to enhance the professional development opportunities for practicing teachers once in schools. Davis et al. (2006) argued that "if teacher educators [including induction professionals] do not understand their learners' needs, then their instructional approaches will be hit-or-miss" (p. 608). Dan Liston et al. (2006) emphasized that the identification of both quality teacher education and induction programs matters: Beginning teachers from quality programs manage personal and professional challenges more adeptly. Further, research is emerging but insufficient to determine the kinds of preservice education that is useful for learning to teach once in an induction context (Wang et al. 2008).

A pressing concern shared by teacher educators, induction professionals, and researchers is how better to support beginning science teachers in enacting reform-minded practices learned in teacher education. Definitions of reform-minded practices vary from student-centered, to constructivist, to conceptual change, to inquiry. Lucy Avraamidou and Carla Zembal-Saul (2005) provided a best-case scenario for learning to teach science as inquiry. They documented how a first-year elementary teacher, Jean, taught science as inquiry in ways that aligned with the goals and practices of both her teacher education program and the *National Science Education Standards* (National Research Council 1996). Jean was typical of a beginning elementary teacher in terms of her age and gender, but atypical in regards the depth of her university science coursework and the quality of her teaching internship. Researchers found Jean adeptly taught science as argument and explanation to her fifth-grade students. She provided students with rich and varied opportunities to give priority to evidence: to collect evidence, record and represent evidence, and construct evidence-based explanations.

Such success stories – however reform-minded practices are defined – are relatively rare in the beginning science teacher literature. More common are studies that document both connections and fractures between preservice education and classroom practice. Thomas Koballa et al. (2005), for example, constructed case studies of three beginning science teachers enrolled in an alternative certification program. They found that only one of these three teachers held views and practices aligned with the goals and instruction of the teacher education program – to teach science in ways that privileged the changing of students' science-related understanding. Similarly, Julie Bianchini et al. (2003) investigated three first-year science teachers' efforts to teach in contemporary and equitable ways. The three were graduates of the same fifth-year teacher education program in Southern California. Each teacher held some views and practices consistent with the goals of teacher education, for example, introducing students to the thought processes and investigative practices of science using open-ended investigations and/or projects. However, each struggled with ways to demonstrate the socially embedded nature of science, to incorporate the knowledge and practices of indigenous cultures, and to highlight connections between science and everyday life. Finally, Winnie So and David Watkins (2005) followed nine beginning teachers from their preservice experiences at one Hong Kong university through their first year of teaching science in elementary grades. They defined teacher thinking along four dimensions: conceptions of teaching and learning, planning, teaching practices, and reflection. As participants moved from preservice education to the classroom, they became more constructivist in their conceptions and practices, and were better able to reflect on their teaching. However, they also became more simplistic in their planning and less coherent across thinking dimensions.

Studies discussed above followed beginning science teachers from their teacher education program through their first year of classroom teaching; much rarer is research that documents beginning teachers' experiences across several years in the teaching profession. Because science teachers' views and practices are thought to evolve over years rather than mere months, such longitudinal studies are all the more important if we are to improve both teacher education and professional development opportunities. Deborah Trumbull (1999) followed six secondary biology teachers from the same US teacher education program through their first 3 years in the classroom. She examined their conceptions of learning, of biology, and of the nature of scientific inquiry. She found that most beginning teacher participants initially lacked subject matter knowledge and struggled to implement their planned lessons; over time, however, their understanding of science and of effective ways to promote student learning grew. In their third year of full-time teaching, most also became more reflective of their practice and critical of how they and others taught students.

Strengths and Weaknesses of Induction Programs

Researchers have also studied induction programs and how these early-career professional development opportunities shape beginning science teachers' views, experiences, and practices. Edward Britton and Senta Raizen (2003) provided one of the few descriptions of induction support received by beginning science and mathematics teachers outside the USA. They found France, Japan, New Zealand, Switzerland, and China exhibited a strong commitment to support beginning teachers and to help address their unique needs. Beginning teachers in New Zealand, for example, participated in a comprehensive induction program to promote early-career learning: to learn how to plan and implement lessons, assess student understanding, work with parents, and reflect on their practice. At their school sites, they were assigned an experienced mentor, participated in peer support meetings facilitated by a school induction coordinator, and sought the advice of a buddy teacher. In addition, New Zealand beginning teachers were given lighter teaching loads and less challenging classes.

In the USA, induction programs are available to some, but not all, beginning science teachers. Thomas Smith and Richard Ingersoll (2004) found that 8 of 10 beginning teachers in the USA participated in a formal induction program. In response to No Child Left Behind legislation and national standards movements, in recent years, such programs have shifted emphasis from concerns about socialization and emotional support to ways to promote teaching and learning consistent with standards (Wang et al. 2008). For beginning science teachers, science-specific induction programs appear more effective in promoting implementation of student-centered, inquiry-oriented instruction than general induction programs or no formal induction support (Luft et al. 2003).

From careful examination of the internal workings of an induction program, Gillian Roehrig and Julie Luft (2006) (see also Luft and Patterson 2002; Luft et al. 2003) found beginning science teachers' preservice training influenced both the kinds of support they derived from an induction program and the ways they taught science in classrooms. Beginning teachers from a teacher education program with strong methods courses and extended student teaching experiences held more student-centered beliefs and implemented more reform-minded practices than beginning teachers from other kinds of teacher education routes. This subset of beginning teachers also used their induction program for philosophical support rather than to expand and enhance their instructional repertoire. Roehrig and Luft cautioned, however, that their study did not shed light on ways school context shaped beginning teachers' learning during induction.

Julie Bianchini and Mary Brenner (2010) investigated both the influence of teacher education and of current school context on beginning teachers' induction experiences. These researchers followed two beginning teachers (one in science and one in mathematics) from different teacher education programs through a 2-year, K–12 induction experience. They focused their investigation on the teaching and learning of equitable instructional practices; they defined such practices as attention to students' experiences, instruction for English learners, differentiation, and reform-minded science or mathematics strategies. Researchers found that previous teacher education experiences and current school communities proved more powerful forces in shaping the ways in which beginning teachers taught science or mathematics to all students than did the induction program under study.

Missing from these and other accounts of beginning science teachers' induction experiences are rich descriptions of students and their learning. Researchers discussed above did not trace the influence of an induction program through changes in beginning science teachers' practices to effects on student learning. Indeed, Jian Wang et al. (2008) found no studies of induction programs did so – in science or in any other discipline.

Beginning Teachers in the Classroom: How School Context and Individual Agency Matter

A third major area of beginning science teacher research examines beginning science teachers in the classroom. Such studies can be divided into two groups: those that examine the influence of school context on beginning teachers and those that investigate the internal workings of teachers themselves. J. Randy McGinnis et al. (2004), for example, investigated the influence of school culture on the instructional practices of five beginning mathematics and science teacher specialists. These five beginning elementary and middle school teachers were expected to teach in reform-minded ways: to teach science for understanding, make connections between science and mathematics, use technology, and implement alternative assessments. Beginning teachers who thought school colleagues supported their efforts to enact reform flourished. In contrast, beginning teachers who worked in less supportive school cultures responded to institutional demands, affordances, and constraints in one of three ways: resistance, moving on to a new school, or exiting from the teaching profession.

Hugh Munby et al. (2000) went one step further in their examination of school context: They studied how school culture shaped not only a beginning science teacher's practices, but her development of professional knowledge as well. These researchers defined professional knowledge as including both practical and research-based competencies. Such professional knowledge, they continued, develops through a process of reframing a problematic situation to identify a new instructional solution. Researchers found that school science (science taught as a predictable process of uncovering new facts within a stable framework) constrained the ways this beginning teacher taught science, the kinds of problems she identified in her instruction, and thus, what she was able to learn from her own teaching practices.

Studies of beginning science teachers' internal workings – their self-efficacy, identity, and knowledge and beliefs – are more common than those of school context. A number of researchers have examined beginning science teachers' self-efficacy (Andersen et al. 2004; Mulholland and Wallace 2001). Ian Ginns and James Watters (1999) also investigated the relationship between beginning elementary teachers' self-efficacy beliefs and their efforts to implement a science program informed by constructivist views of learning. They found self-efficacy beliefs did not fully account for these beginning teachers' decisions to implement constructivist lessons; they noted the need to examine other factors such as volition, motivation to teach science, and the experiences of success. Along similar lines, Ken Appleton and Ian Kindt (1999) argued for the importance of attending to beginning teachers' sense of self-as-teacher. They studied nine elementary teachers who had graduated with high marks in their science education courses from one teacher education program in Australia. One of four factors found to shape their teaching of science was self-confidence. Researchers suggested beginning teachers' teaching of science might be related to positive or negative self-images of themselves as teachers.

Several other researchers (Proweller and Mitchener 2004; Varelas et al. 2005) have studied beginning science teachers' development of personal and/or professional identities. Maria Varelas et al. (2005), for example, explored how beginning science teachers' identities as practitioners of science and practitioners of science teaching were shaped by participation in a science research apprenticeship experience. Researchers found differences in beginning teachers' scientists and science teacher identities. They argued that the concept of hybridity allows such differences to be seen as opportunities for teachers to build bridges between their experiences in their lab and in their classroom to eventually challenge and reshape both kinds of practices.

Finally, beginning science teachers' beliefs and knowledge have also been investigated. Patricia Simmons and colleagues (Simmons et al. 1999) identified matches and mismatches between beliefs and classroom practices. Researchers found that many more first-year science teachers espoused student-centered beliefs than enacted student-centered practices. By their third year, many beginning teachers exhibited both teacher-centered beliefs and practices. In their study, Brenda Gustafson et al. (2002) examined the effects of a limited mentoring experience on the development of professional knowledge in 13 beginning elementary science teachers in Canada. Researchers found visits to and conversations with experienced teachers enhanced beginning teachers' general pedagogical knowledge; to a lesser extent, their curriculum knowledge; and to an even lesser extent, their subject matter knowledge, pedagogical content knowledge, and knowledge of learners. Rather than investigate beginning science teachers' beliefs or knowledge, Barbara Crawford (2007) chose to look at views. She defined knowledge as being empirically based, rational, and highly structured; beliefs, as subjective, connected to emotions, and embodying personal experiences. The use of the word views, she argued, highlights the interplay between a teacher's knowledge and his or her beliefs.

Possible Directions for Future Research

In the above discussion of existing research on beginning science teachers, two possible avenues for future study emerged. First, more studies that follow beginning science teachers from preservice teacher education through several years – rather than 1 year – of classroom practice are needed. Second, missing from the research literature are studies that trace mis/connections across induction training, beginning teachers' classroom practices, and student learning. Below, I describe in greater detail these and other possible avenues for strengthening research on beginning science teachers.

Theories of Beginning Teacher Learning

One way to strengthen research on beginning science teachers is to foreground the theory of teacher learning framing the study. Careful selection and explicit use of a theory of teacher learning should help researchers better align research purposes to methods used, findings presented, and/or implications identified. Liston et al. (2006) outlined four different frameworks researchers have used to investigate teacher learning. A stage theory of teacher learning describes teaching as beginning with survival during the first few months and ending with mastery achieved some time in the fourth year. Stage theories have been criticized, however, for presenting learning to teach as a linear process impervious to the influences of school contexts. A second, more recent framework presents teacher learning as adaptive expertise: Such expertise is conceived as existing along the two dimensions of efficiency and innovation. Progressive differentiation, a third framework, outlines five levels of knowledge drawn on by teachers as they learn. Finally, learning to teach can be conceived as a continuum where the central learning tasks for preservice, beginning, and experienced teachers differ. Such a continuum underscores that learning to teach takes place in different contexts with different supports. Indeed, such a continuum (Feiman-Nemser 2001) was used to introduce this chapter on beginning science teacher research.

In the science education literature on beginning teachers, explicit use of any of these four frameworks for learning is rare. More common are general theories of learning, for example, learning as socially constructed or culturally situated. In a recent study I conducted with a colleague (see Bianchini and Cavazos 2007), we described beginning teacher learning as both social and situated. More specifically, we employed Marilyn Cochran-Smith and Susan Lytle's (1999) definition of teacher learning as a process of generating knowledge of practice and identified three interconnected sets of opportunities beginning science teachers could use to learn to teach toward equity: from students, from inquiry into their own practice, and from teacher learning communities. This description of teacher learning emphasized learning as a means to improve teachers' own work and to eliminate school and societal inequities. It aligned well with the purpose of the study: to identify if and how beginning science teachers promoted equity and diversity in their own classrooms. It also provided the organizational structure for the study's findings.

A better sense of the kinds of insights generated from coherence across a theory of teacher learning, research purposes, and, in this case, research methods can be found in a study by Paul Adams and Gerald Krockover (1999). Their study was framed by George Kelly's (1955) personal construct theory of learning: This theory describes how recalled memories shape current teaching constructs. Their purpose was to help one biology teacher, Bill, enhance his implementation of constructivist teaching practices, such as the negotiation of key ideas with students, student-generated investigations, and multiple forms of assessment. To do so, researchers collected data using a constructivist-based observation instrument. Researchers asked: In what ways might this observation instrument stimulate recall of constructivist teaching practices advocated in Bill's teacher education experiences? How might these recalled experiences impact his teaching of reform-minded science? Teacher education programs, the authors concluded, must provide support and transition activities during the first critical years of teaching to help beginning teachers bridge the journey from a traditional student of science to a constructivist science teacher.

Varying the Grain Size of Studies

A second possible way to strengthen research on beginning science teachers is to more regularly vary the grain size of studies – to increase the number of participants included, diversify the kinds of teacher education routes examined, and/or lengthen the time the study is conducted. Most research discussed in this chapter presents qualitative case studies of one to several beginning teachers from the same teacher education program. These kinds of studies have an obvious strength: Researchers can clearly articulate mis/connections across the teacher education setting and beginning teachers' views and practices. Because the structure, goals, and experiences in one teacher education program can be thoroughly and comprehensively documented, researchers can ascertain how to better support beginning teachers both within and once outside their teacher education experiences. Limitations to these kinds of studies are also obvious. It is difficult to generalize the experiences of a few beginning teachers to many, for example. It is also impossible to compare and contrast the strengths and limitations of different approaches to the education of preservice or beginning teachers.

One way to vary the grain size of studies was already discussed above: following beginning science teachers across more than 1 year of classroom practice. A second possibility would be to increase the number of beginning science teachers selected for study. Annemarie Andersen et al. (2004) provide a rare example of a study with a large number of beginning science teacher participants: They administered three rounds of surveys to 39 (the initial sample size was 66) first-year elementary teachers in Denmark. Participants were graduates of the same teacher education program and had specialized in science. The researchers' purpose was to better understand how school context interacts with self-efficacy to affect the quality of science teaching. A study conducted by Gili Marbach and J. Randy McGinnis (2008) is a second exception: They surveyed 31 reform-prepared elementary and middle school science teachers from the Maryland Collaborative Teacher Preparation program to determine to what extent views and practices were maintained once teaching full-time in classrooms. The two researchers argued that more studies with larger numbers of participants are needed to understand if and how beliefs and practices introduced in teacher education are maintained and/or enacted once in the classroom.

Similarly, researchers might more often investigate beginning teachers from different teacher education institutions or induction programs. Roehrig and Luft (2006), discussed above, included beginning teacher participants from four different teacher education programs in their study of a science-specific induction program. They found a beginning teacher's teacher education program influenced both her/his implementation of reform-minded practices and the kinds of support derived from the induction experience. Simmons et al. (1999), also discussed above, included both a large sample size – 69 beginning science and mathematics teachers – and diverse teacher education programs – a total of nine – in their 3-year study. Unlike Roehrig and Luft, however, Simmons and colleagues did not separately examine beginning teachers from different teacher education programs.

What Is Missing? Connecting Beginning Teachers' Views and Practices to Student Learning

As stated above, at present, there are no studies of induction programs that include examination of student learning. Further, none of the studies of beginning science teachers discussed in this chapter examined mis/connections between beginning science teachers' views and practices and their influence on student learning. Examination of student learning appears a crucial but missing link in the literature on beginning science teachers. A few studies of beginning teachers do highlight the importance of attending to students without directly studying them. Helen Meyer (2004), for example, examined how teachers understand the concept of student prior knowledge and make instructional decisions based upon this understanding. She compared preservice and first-year interns' conceptions of learners' prior knowledge to those of expert teachers. What was unexpected was novice teachers' lack of strategies for finding out their students' prior knowledge. Novice teachers defined prior knowledge as learned science content, used activities to elicit what facts students knew, and then attempted to add on more information. Expert teachers, in contrast, focused on their students: They defined students' prior knowledge more broadly, intentionally designed activities that had students explain their prior knowledge, and then worked with their students' ideas by shifting between science content and life experiences.

Amira Proweller and Carole Mitchener (2004) used the theoretical lenses of race, ethnicity, and social class to explore relationships between beginning science teachers and their urban middle school students. As teachers discovered the diversity of experiences among their students, they found themselves rethinking the assumptions about who urban youth are and the kinds of lives that they lead that they had brought with them into the classroom. Beginning teachers came to understand that forging relationships with urban youth depended on learning about students' families and communities. They also discovered that science needed to be taught in personally relevant and socially contextualized ways to create powerful learning opportunities for students – opportunities for students to better understand themselves, others, and the world around them.

To repeat, student learning appears a crucial but missing piece of research on beginning science teachers. Because beginning science teachers are both teaching and learning to teach, it seems somewhat ironic that their students' learning of science does not figure more prominently in studies of their views, experiences, and practices. Ultimately, it matters little how successful a teacher education or induction program is in aligning beginning teachers' views and practices to the goals of science education reform if student interest in and understanding of science is not enhanced.

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Chapter 28
Developing Science Teacher Educators' Pedagogy of Teacher Education

Amanda Berry and John Loughran

Science teacher education has been characterized as a technical-rational approach whereby science teacher educators deliver knowledge about teaching to prospective teachers in the form of theories and/or 'activities that work' (Appleton and Kindt 1999, p. 164). Underlying this approach is an assumption that knowledge about science teaching can be translated directly into practice and that prospective science teachers' professional knowledge can be developed independent of their experiences of teaching (Russell and Martin 2007). Exacerbating this situation, many prospective science teachers enter their pre-service programmes with strongly held beliefs about the nature of science knowledge as 'unproblematic … [whereby] [s]cientists are regarded as experts whose views have authority conferred on them by the power of the scientific method and its universal applicability' (Bencze and Hodson 1999, p. 522). Therefore, practices related to being a science teacher often carry 'a heavy reliance on didactic teaching styles' and a 'cookbook' approach to investigative work (p. 522) – a consequence of years of experience as learners of science. This situation presents a problem for science teacher educators: How can student teachers be stimulated to think about teaching and learning and science in ways that differ from a system in which they have been successful?

The job of the science teacher educator is complex. There is a need to challenge the image of teacher as technician in expanding prospective teachers' views of teaching (Clark and Lampert 1986). There is also a need to respond to the ongoing calls for science teacher education reform in ways that will positively impact the needs, concerns, beliefs and expectations of students. Doing so requires a sharper focus on the knowledge of teaching about science teaching and learning, that is, developing richer understandings of a pedagogy of teacher education (Korthagen 2001).

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This chapter takes up the challenge to science teacher educators to pursue relevant, meaningful and applicable research so that learning about teaching science informs and enhances the experiences for all participants in the processes and practices of teacher education (Loughran 2007b).

Self-study

Self-study of teacher education practices (S-STEP) emerged partly in response to ongoing calls for teacher education reform and the hopes of teacher educators to be integral to such reform. Self-study is about teacher educators researching their teaching about teaching and their students' learning about teaching. With its genesis in action research, reflective practice and teacher research self-study grew and developed in ways that dramatically extended these fields through a teacher education context.

Despite the natural attraction of self-study, it is important that self-study goes beyond the self to genuinely impact on the work of teacher educators more widely. Through self-study, teacher educator practitioner research accounts of the dilemmas, issues and concerns germane to teaching *and* learning about teaching need to be available for public critique and scrutiny but need to inform knowledge of practice. This is critical to shaping what happens, how and why, in the work of other teacher educators and teacher education programmes.

It is this need for self-study to be more than 'just another story' (Loughran 2007a, p. 14) that matters to many self-study researchers (e.g. Berry 2007; Brandenburg 2008) and has been important in maintaining scholarly expectations in the self-study community. At the heart of self-study is an ongoing push for teacher educators to take seriously what they do, how and why, in their teaching of teaching so that their student teachers might become purposeful and professional educators. The expectation being that student teachers will understand teaching as problematic and feel comfortable working with the uncertainties of practice as they develop and extend their expertise in accord with that modelled by their teacher educators.

The development of knowledge is clearly important if there is to be progress in teaching and learning about science teaching. One aspect of knowledge development that self-study encourages is a teacher-as-learner stance and, many of the learning outcomes from research into such things as alternative conceptions (Pfundt and Duit 2000), prior views (Gunstone 1990) and engagement in science learning (Millar 2006) have been important in directing the focus of some science teacher educators' inquiries into their own practices.

Some self-study researchers have actively sought to examine the processes and practices of science teaching and learning in their own teacher education classrooms in an attempt to address the stereotype of school science teaching as the simple transmission of facts (Goodrum et al. 2001). This chapter offers an overview of some of this research as it is enacted in a pedagogy of teacher education (Russell and Loughran 2007) as developed through the work of science teacher educators who have adopted a self-study methodology.

Elementary Science Teacher Education

A feature of some self-study projects is related to the need for teacher educators to pay attention to their students in ways that offer insights into their own practice. This approach to learning about teaching has consequences as Cynthia Nicol (1997, 2006) discovered because there is a need to differentiate between 'listening for' and 'listening to' students, that is, 'listening for' those things that are only on the teacher's agenda in contrast to 'listening to' that which students say or imply (Nicol 1997, p. 112).

Azza Sharkawy confronted what it meant to really listen to her students in her early experiences of teaching elementary science methods classes. With a critical friend (an important aspect for many self-studies) she examined this experience.

> Listening non-defensively in a way that invites self-critique is difficult work. It is, after all, possible to identify tensions in teacher education without using them to inspire deep reflection and reframing that can help to work more effectively with the tensions. Recognizing the complexity of teaching and learning reinforces the fact that professional development and growth are processes that require time and systematic effort. (Sharkawy and Russell 2008, p. 290)

As the following studies demonstrate, listening, seeking critique on one's own practice and learning from those experiences demands a lot from a teacher educator. Self-study encourages listening in ways that can help teacher educators understand and respond appropriately to their learners' perspectives.

Teacher Educators Learning from Their Students

Andréa Mueller (2004) was drawn into self-study for reasons similar to those of many other elementary science teacher educators. As a beginning teacher educator, the experience of her first year teaching teachers highlighted for her that she needed to better connect with her students so she developed ways of accessing their reflection. As a consequence, she began to learn about her teaching of elementary science to her student teachers through their experiences and through their reflective accounts of those experiences. Through collaboration with a critical friend, she learnt to reconsider and refine her teaching of teaching in five specific ways. These included:

- Changing the design of her major reflective practice assignment
- Changing the nature of her responses to student teachers
- Taking more time for discussion in class

- Being explicit in classes about what she did as a teacher educator
- Allowing herself to make changes as the need arose

Her desire to better understand how to help her student teachers learn about teaching *and* learning science was the catalyst for her involvement in a study that impacted her practice. By examining her students' reflective accounts as data, not just as university assignments/tasks, she saw her own practice anew. This led her to reconceptualise her 'own teaching as problematic and [to] share this knowledge with preservice teachers and colleagues [which further helped] change [her] practice' (p. 151).

Focusing on student teachers' reflective accounts is a theme that is taken up by a number of beginning teacher educators. Brenda Capobianco wanted to learn about her students' experiences of her attempts to implement technology into her elementary science teaching programme, based on an inquiry-based approach (Capobianco and Lehman 2006). She found that 'as pre-service teachers make decisions about their own teaching, experience it, and reflect upon it in the context of their preparation programme, they are better able to construct educational understandings that are similar to those espoused by the teacher educators' (p. 143). As a novice science teacher educator she decided to share her personal reflections with her student teachers, which helped her begin to 'conceptualise the relationship between the modelling of reflective practice and its development in, and use by, preservice science teachers' (p. 290).

In a similar vein, Garry Hoban (1997), an experienced teacher educator, was also concerned to better understand his elementary science student teachers' learning about teaching in his classes. He adopted a much more personally confronting approach in his self-study. He sought direct and honest feedback from his student teachers about their experiences of learning science in his classes.

Aware that elementary science teachers are commonly uncomfortable in science practical classes because of their perceptions about their own lack of science content knowledge, Hoban asked his student teachers to use 'a journal to critique [his] teaching each week by recording and reflecting on their positive and negative learning experiences during the practical class[es]' that he organised and ran for them (p. 135). Hoban soon realised that there was much more to learn from inquiring into his teaching than he had previously anticipated. His learning was twofold: what his students learnt in terms of science content through class instruction; and, how they learnt that content, that is, their meta-cognitive processes in monitoring and analysing their own learning.

Hoban developed new ways of teaching about elementary science teaching and felt that he made certain breakthroughs around student teachers' perceptions of theory and practice. He was taken by the fact that through critiques of his own teaching, his student teachers came to better understand the 'complexity of learning and inappropriateness of "recipe" teaching approaches' (p. 146); something that the literature continually demonstrates is a paradox for the majority of student teachers and a source of frustration to many teacher educators. Through a focus on metacognition, some of his student teachers were able to move beyond the mental block they had developed towards science despite their negative attitudes about the subject from their previous schooling experiences.

Attitudes Towards Science Curriculum

Gilda Segal developed a three-part gender-inclusive learning and teaching model (Segal 1999) for 'alienated elementary teacher education students' (p. 24). She studied how both she and her students learnt about the science of refrigeration. The programme redesign included working from her students' prior views, stimulating them to embark on scientific enquiry and supporting their learning through cooperative group work. Her eyes were opened to many aspects of science teaching and learning that she might otherwise have overlooked had she only concentrated on the curriculum package itself.

Segal became 'much more sensitive to the nuances of how to entice students to make an initial plunge into contexts they might not find attractive' (p. 20). She found that the necessary equipment to conduct a practical enquiry can itself be a barrier to student engagement in the content and, in terms of pedagogy, that 'once students took their first tentative steps towards a context that held no initial attraction for them, [she] learned how slowly [she] should advance' (p. 20). There was also a reminder that relationships matter, including those between the learner and the science context and an ongoing need to address anxieties borne of previous science learning experiences.

Carol Mitchener (2000) also drew attention to the relationship between the learner and science content. She did this by seeing two aspects of the relationship simultaneously. One was that of the teacher–student relationship so common to thoughtful pedagogy; the other was the relationship between teaching and that which a learner makes with the content itself. Mitchener came to 'more fully recognize and feel the depth of [her] commitment to helping children develop a relationship with science, and not just knowing [science]' (p. 186) and this became a touchstone to her role as an elementary science teacher educator.

Integration: Taking Science Learning from Pre-service into Schools

Sandra Blenkinsop and Penelope Bailey (1996) confronted the concept of subject integration in their self-study. They were interested in challenging their students' initial 'foggy impressions of integration' (p. 224) in order to help them develop richer understandings of the ways in which 'various types of reading and writing could be used in the process of scientific inquiry' (p. 224). Not surprisingly, they found that, for many of their students, there was a washing out effect when they moved out into their school practicum internships; especially for those who did not have a strong commitment to 'hands-on inquiry science' (p. 224).

Their study led them to realise the importance of helping their students see that teaching reading and writing within the context of science is not a just an add-on or fun activity, but a central aspect of science teaching for meaningful science learning.

Similarly, Sandy Schuck and Gilda Segal (2002) became aware of the fading effect of their innovative pre-service teaching when they conducted a collaborative research project with their graduates. Their study highlighted a number of issues that impacted not only their understanding of beginning teaching, but also the manner in which they needed to reconsider what they did, how and why, in their teacher preparation programme:

> … most of the beginning teachers had embraced our socio-cultural views of teaching mathematics and science, and were keen to put into practice their beliefs about how mathematics and science should be taught. However, we observed some large barriers to the reforms. … tension between school realities and beginning teacher ideals often created a great deal of frustration for the new teachers … major difficulties that the beginning teachers mentioned related to school contexts with which we had not dealt explicitly in our subjects. These difficulties included specific dilemmas in classroom management, the requirement to teach from another teacher's program, and a lack of time for science teaching and hence little increase in expertise and self-confidence in science teaching. (p. 93)

Learning with and from elementary teachers was also a theme in the examination of students' science learning interests through the School Museum Integrated Learning Experiences in Science Project (Pressick-Kilborn et al. 2006). Again, understanding the self and how that self is shaped by previous teaching and learning experiences stood out as important. In particular, and in accord with Schuck and Segal above, self-confidence and independence are crucial to fostering teaching that supports learner-centred approaches to science.

These accounts of researching practice demonstrate that there is a clear need for science teacher educators to experience and understand learning about science teaching *and* learning in ways that challenge their existing taken-for-granted assumptions about practice. Science teacher educators' learning appears to impact not only the way they teach their student teachers but also the way their student teachers think about their own teaching of science to their students. That is an important outcome that creates a genuine challenge to the status quo in elementary science teacher education. What it means in secondary teacher preparation programmes is explored in the next section of this chapter.

High School Science Teacher Education

Science teacher educators are often drawn to self-study through the dilemmas and challenges they face in understanding and managing the relationship between their students' learning to teach science and their own efforts in supporting that learning.

Many science teacher educators are themselves former science teachers, so their transition from teacher to teacher educator often highlights that their experiences of teaching science is, in itself, insufficient as a basis for a pedagogy of science teacher education. Teaching about science teaching is different from classroom science teaching, and knowing what to do and how to do it is far from clear or straightforward.

Shawn Bullock (2009), a newly appointed physics teacher educator, found his transition experiences more challenging than he anticipated as his identity as a physics teacher did not serve him in the way that he had hoped. While Bullock believed in the importance of providing opportunities for learners to develop and trust their own voice, he found that this was not so easy for him to live as a teacher educator as student teachers wanted him to tell them what he knew about teaching physics. While initially he felt an urge to fulfil their need to be told, he learnt how to enact an alternative approach that was more consistent with his beliefs. Through recognising particular aspects of his teacher educator behaviour, Bullock drew parallels between his experiences of classroom teaching and teacher education that helped to better inform his developing pedagogy of teacher education.

> There was an awkward moment in class today when one of my teacher candidates, who is working toward certification as a science teacher, asked me what I thought about doing a lab at the end of every week over the course of a unit. Her logic was that students would 'get more' out of the lab if she was sure that they clearly understood the concepts beforehand. …. I was horrified when I realized that I wanted to plainly disagree with her. I wanted to tell her the 'right' answer. (Personal Journal, September 2006)
>
> Fortunately, I was able to hold my tongue and suggest that she try a variety of approaches to teaching laboratories over the practicum. I was surprised at how much I wanted to tell someone how to teach. The experiences reminded me of how I struggled with the differences between telling students about physics and teaching students about physics early in my career. That moment in class helped to frame my future learning as a teacher educator. (p. 296)

As a beginning science teacher educator, Rebecca Cooper learnt that even though she was prepared to share her considerable expertise as a science teacher with her student teachers, they did not take on board her ideas in the ways she anticipated. Simply telling them what she knew did not impact their practice. As a consequence of her self-study (Cooper and Keast 2008), she came to realise that her interpretations of her student teachers' needs was different from the needs they expressed for themselves: 'I had to be willing to engage in discussion that began from where my students were at rather than from my own needs as an experienced teacher' (p. 80).

Peter Chin (1997) pursued deeper understandings of his practice as a chemistry teacher educator through articulating his core beliefs and investigating how these beliefs played out in his practice. He learnt that student teachers needed to have opportunities to experience and make sense of what he sought to help them understand, but that just providing such opportunities was not enough. He came to recognise that student teachers also needed to experience some dissatisfaction with their current ways of thinking for them to consider, or try out, the alternative approaches to teaching that he was promoting.

> Even if pre-service teachers recognise the intelligibility, plausibility and potential fruitfulness of the teaching approaches I advocate in the science methods course, my efforts are fruitless unless they are personally dissatisfied with some facets of their current conception of teaching. (p. 122)

In many ways, Chin was developing a pedagogical stance that was based around the need for his own practice to model a constructivist approach. He concluded, 'learning about teaching best occurs through shared experiences and critical discussions' (p. 123), a view that stands in stark contrast to more traditional science teacher education approaches that are commonly reported as comprising the status quo. Facilitating a constructivist perspective is then one way of challenging the existing position.

Facilitating a Constructivist Perspective

A dominant theme across science teacher educators' self-studies is a concern to incorporate a constructivist perspective into their teaching about science teaching. This is typically developed through an emphasis on promoting opportunities for student teachers to experience self-directed learning and problem solving in order to promote 'a more authentic view of science and scientific practice' (Bencze and Hodson 1999, p. 521). In this way, science teacher educators hope to encourage their student teachers to learn about their students' experiences of grasping the science content, and as a consequence, to organise experiences in their own classrooms to help their students develop other and better ways of understanding the content (Trumbull 2004).

Karen Goodnough (2003), a teacher educator responsible for the preparation of middle and high school science teachers, sought 'to foster, in [pre-service science] students, an inquiry-based approach to teaching by modelling constructivist approaches in [her]… own teaching' (p. 18). She explored the use of problem-based learning (PBL) as an instructional approach in her science methods class in order to provide her students with opportunities to construct richer understandings of science concepts through specific science problem scenarios.

Through developing their understanding of the nature and use of PBL by experiencing it, Goodnough anticipated that it might help her student teachers make stronger links between science content and pedagogy, and in the process develop student teachers' (and her own) pedagogical content knowledge (PCK). As a consequence of her self-study, Goodnough found that her knowledge base for teaching about PBL changed, but not in the way she had expected. She came to learn more about how she organised the experiences of learning through PBL, and what she did or did not do, to enhance student teachers' learning opportunities:

> In retrospect, I should have started with one small problem before introducing several in my course. When I collaborate with teachers, I always tell them to start small when trying something new. I did not heed my own advice. (p. 3)

Embarking on a self-study helped her to see differences between what she advocated for others and what she did in her own practice. This is an important realisation that is central to facilitating change in a teacher educator's practice.

Peter Aubusson (2006) also used a project based teaching approach similar to PBL with his pre-service secondary science teachers as a means of modelling more authentic approaches to science learning. In order to help his student teachers examine their experiences of this open-ended approach, Aubusson modelled the use of metaphor and analogy as a tool for analysing and communicating their thinking along the way. He encouraged class members to share and comment on each other's analogies and metaphors, including his own.

Although familiar with the use of metaphor and analogy as a means of 'inform[ing] personal analysis of ideas about teaching' (p. 102), he was taken aback by his students' responses to his metaphors. This experience led him to view aspects of the teaching/learning relationship as problematic in ways that he had not previously recognised or considered. Although he had not expected to be the learner himself, it was he who most benefited from the chosen approach.

> I had entered into the task lightly; being familiar with metaphor use, the modelling did not seem threatening. Strangely as a researcher I was aware that metaphorical analysis serves to reveal the unknown but as a teacher I had not anticipated that it might reveal things that I did not already realise. (p. 107)

Through genuinely engaging in the learning experience with his students, Aubusson's understanding of the problematic nature of engaging in an inquiry approach was greatly enhanced.

Deborah Trumbull (2006) used a reflective approach to teaching her student teachers about the uncertainties and complexities of science teaching. Through sharing entries from her teaching journal with her pre-service maths and science teachers, Trumbull intended to model 'the kinds of attitudes of a reflective teacher' (p. 68) and provide insights into 'what engaged [her], as a teacher and as a person' (p. 68). She hoped that her student teachers might be stimulated to think more deeply about what engaged them as teachers through offering access to her thinking about teaching processes.

Her self-study evolved over several years and involved a systematic exploration of student teachers' responses to her journal. Her data revealed a surprising finding: her student teachers did not comment on her reflections about her science content knowledge. Through her self-study, she came to realise that if she wanted student teachers to engage in discussions of science content with her (and each other) then she needed to develop more purposeful ways of inviting them to do so. Her insights led her to: be more directed in the selection of reflections to share with her students; be more explicit about what she asked her students to comment on with regard to her reflections; and provide opportunities to make reflection a shared, public activity rather than something private and individual.

These studies illustrate how some science teacher educators have come to a position whereby their need to articulate what they are doing, how and why matters not only for the development of knowledge about science teacher education, but also because of the underlying value of doing so for enhancing the science education experience of student teachers. Articulation of practice and purpose is at the heart of a pedagogy of teacher education.

Articulating a Pedagogy of Teacher Education

Tom Russell, an experienced physics teacher educator, was concerned to understand how to make his knowledge of teaching physics more accessible to his student teachers in ways that could prompt them to reconsider their views of physics and physics teaching (Russell 1997). He recognised that many student teachers entered their teacher preparation programmes with traditional views of teaching as telling; where physics teachers were holders of 'the right answers' (Russell and Martin 2007, p. 1173), and physics teaching was concerned with the delivery of facts.

Russell modified his physics methods programme, using teaching approaches such as Predict-Observe-Explain (White and Gunstone 1992), which were consistent with his ideas of actively engaging students in constructing their understanding of physics concepts. As a consequence of his self-study he came to recognise the powerful influence of the way he taught, compared with what he taught in his physics method classroom: '*How* [author italics] we teach must be a major focal point for all who are concerned with teaching and learning science and how individuals learn to teach science' (Russell and Martin 2007, p. 1173). Based on analysis of his journal entries as well as feedback from students and colleagues, Russell was able to articulate the frames that guided his practice, and to reframe understandings of practice as his experiences in the physics methods classroom led him to understand his practice differently. Across the range of self-studies he has published, there is an ongoing focus on his learning as a consequence of exploring his own and his students' understandings of learning to teach physics in ways that inform and shape his practice in the physics methods classroom. In so doing he actively develops and articulates a pedagogy of teacher education.

John Loughran was also concerned with challenging traditional approaches to science teaching as the transmission of propositional knowledge. He sought to offer 'alternative experiences of being engaged in science' (Loughran 1997, p. 57) to his student teachers. By '[p]lacing student teachers in a genuine learning about teaching context … us[ing] [his] own learning about a concept to drive [his] teaching about teaching – [he] actively consider[ed] (and reconsider[ed]) how [he] learn[t] and came to understand content knowledge - so that it directly influence[d] how [he taught] that content knowledge' (p. 66). This experience led him to see the need to be able to articulate his principles of practice based around the themes of: relationships (trust, independence); purpose (engagement/challenge); and, modelling (reflection, risk taking) – themes that resonate with many of the studies reviewed in this chapter.

Loughran's own involvement as a learner in teacher education significantly impacted his understanding of the teaching/learning relationship. He came to recognise the value for learners of science teaching (including himself) to experience the teaching procedures being advocated in order to more deeply understand their potential for learning particular science content (learning through modelling). For instance, through developing and participating in a role play with his students about the relative movements of the earth and its moon, Loughran experienced the powerful effect of making the abstract concrete (a problem commonly experienced in science teaching) and that there is so much more to role play than simply playing a role (a problem in the use of this procedure in science teaching):

> Suddenly I got what it meant to be involved in a role-play. Suddenly I saw a number of important pedagogical insights. Suddenly content matter started to take new shape as a developing understanding slowly emerged. Suddenly, our class became alive with learning; and I was part of it. … After the class I mused over the episode again. …[W]hat I knew – or thought I knew – before the experience was dramatically different to what I knew after the experience. Being involved in the experience was different to directing it for others. Abstracting the learning from this experience to other situations was intellectually challenging and engaging. What I saw in my students' approach to learning about teaching was new and different. What I began to see in teaching about teaching was a revelation. What I previously knew, I now understood. (Loughran 2006, p. 26)

An important aspect of this development of a pedagogy of teacher education is in the dual role of teacher and learner and how that plays out in the way student teachers learn about science teaching. Teacher education is then a context in which teacher educators and student teachers together can begin to examine some of the assumptions and problems of practice and to begin to think more deeply about what that means for quality in the teaching *and* learning of science. This point is developed further through Amanda Berry's research.

As a biology teacher educator, Berry identified a set of seven tensions regularly experienced by teacher educators as they learn to recognise and manage differences between their needs and concerns as teacher educators and those of their student teachers (Berry 2007). For example, one of these tensions, resonating through the studies reported in this chapter, is that of 'telling and growth' (p. 45): the competing feelings experienced by teacher educators of wanting to tell their student teachers about teaching through the transfer of experience or propositional knowledge, and providing opportunities for student teachers to grow through self-directed experience and personally constructed knowledge.

Berry's extensive self-study, conducted over 1 year with her biology methods classes, drew on data from colleagues, students and her own reflections about her teaching and her students' learning from these classes. Conceptualising her practice as tensions to be managed, she was able to recognise fundamental differences between the concerns of teacher educators to develop student teachers' understandings of practice, and student teachers' personal concerns (at least initially), to satisfy their need to know about technical aspects of practice. As a consequence of being able to articulate her understandings of her practice in this way, Berry was able to recognise and effectively build on a pedagogy of teacher education.

While many of the self-studies reported by science teacher educators concern their experience in their university context, a small number of self-studies have been conducted by science teacher educators returning to teach in schools.

Experienced Science Teacher Educators Return to the Classroom

Jeff Northfield (Loughran and Northfield 1996) returned to the classroom after 20 years as a teacher educator, and undertook a year-long examination of his teaching with a class of year 7 (first year of high school in Australia) students. With the support of a critical friend, he analysed his experiences of his teaching and his students' learning in science and mathematics, as a means of trying to better understand and inform his, and others', teacher education approaches. However, as he quickly discovered, simply doing teaching in a different context is not the same as learning about teaching and so he came to question some of the underlying assumptions about the mantra of recent and relevant school teaching experience:

> … the connection between school experience and improvement in teacher education is not clear. Although we would argue that greater opportunities should exist for teacher educators to work in schools and classrooms, the experience alone is not sufficient. Certain conditions for learning about teaching and teacher education need to be established to make the effort worthwhile. (p. x)

Northfield's experiences were important in shaping how he came to reconceptualise and articulate his teaching as derived from his learning about teaching in a school context. This learning through experience was also evident in the work of Russell who similarly chose to return to high school science teaching to inform his pedagogy of teacher education.

Tom Russell returned to the high school physics classroom after a long absence in order to better understand what his physics method students were learning to do and to test his abilities against the current realities of physics teaching (Russell 1995). Like Northfield, Russell also 'made [him]self a data source for [his] continuing study of teachers' development of professional knowledge' (p. 95). He came to recognise that his '[r]eal professional learning' emerged as a consequence of 'the intense often chaotic experiences of the first year' (p. 107). As a consequence of his experiences he came to recognise anew the importance of listening to his own voice and learning from experience.

Both Russell and Northfield experienced their first year (back) in school as chaotic and intense, and that dramatically informed what they did, how and why with their student teachers in their university-based teacher education programmes. Russell went on to a second year of high school teaching and found that his learning really began to flourish as he was able to analyse his experiences more effectively; all of which he found enhanced his teaching of science teaching. Northfield pursued his professional knowledge development through a deep and rigorous analysis of his data with a colleague that led to a book about his experience. Importantly, both Russell and Northfield learnt that 'learning about teaching cannot be conducted alone' (Loughran and Northfield 1996, p. 139).

A major learning outcome from both of these studies is in the importance of articulating knowledge of practice – regardless of the setting. For Northfield, the change in teaching context dramatically highlighted: 'the types of tacit knowledge that teachers develop as part of their teaching role … [These] tacit experiences must be made explicit if we are to consider alternative frames of reference that may lead to a deeper understanding of teaching and learning' (p. 140).

Making the tacit explicit, building the knowledge of science teaching and learning practices in ways that are accessible and useable by teacher educators and their student teachers is fundamental to a pedagogy of teacher education and is a meaningful response to the calls for science teacher education reform.

Conclusion

Research on the development of science teacher educators' pedagogy of teacher education is a relatively new and growing field. The studies reviewed in this chapter illustrate that the development of understanding of teaching and learning about science teaching is an individual and evolutionary process that tends to focus on teacher educators examining the ways in which their beliefs and values might (or might not) be enacted in their practice. At the same time, while this work is often deeply personal and context bound, it is also a 'big-picture enterprise' (Russell 2007, p. 190) as the knowledge of teaching and learning about science teaching that is developed is articulated and portrayed in ways that seek to impact the work of others.

In our view, developing a pedagogy of science teacher education requires educators to be awake to, and aware of, the complex and problematic nature of science and of teaching, as well as having a preparedness to create and engage in experiences that enable genuine learning to take place for all participants in the learning to teach process. In this way, possibilities for developing and enacting approaches to science teaching that can seriously challenge taken-for-granted models can be encouraged to develop so that real alternatives for learning that is meaningful and applicable in school science will emerge.

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Chapter 29
Using Video in Science Teacher Education: An Analysis of the Utilization of Video-Based Media by Teacher Educators and Researchers

Sonya N. Martin and Christina Siry

There is an increasing trend toward incorporating video[1] and multimedia into teacher education for both K—12 pre- and in-service teachers of science. Our purpose in this review chapter is to examine the trends involving video usage in science teacher education and science education research that we have noted in the literature, both recent directions as well as early uses of video. We begin by tracing some developments in video technologies and exploring examples of the ways in which video/multimedia have been utilized in the education of science teachers. We also focus on some of the web-based technologies and software that enable educational researchers and teacher participants to edit video content (both from their own classrooms and others) and then author and share their analyses of the video with a larger teacher or educational research community. We note a growing emphasis in science teacher education toward having preservice and in-service teachers developing electronic portfolios, including video vignettes of teacher practice with reflections as evidence for development as critical practitioners. We conclude by offering implications and raising questions for future research on the utilization of video and multimedia technologies in the preparation and professional development of science teachers.

[1] In our discussion of video, we use the term video in reference to recorded images and sound. When we make a distinction between videotape and digital video, it is to denote the method used to store and access recorded images and sound.

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Video Technologies and Teacher Education

Over the last 50 years, technologies for recording, storing, and showing video have become more affordable, portable, and accessible for general consumers as well as educators. Currently, digital video cameras no larger than a box of crayons can be purchased for about US$100 (e.g. FlipVideo http://ca.theflip.com/), which record 60–120 min of video that can be transferred immediately via a USB connection to a computer for instant digital editing and analysis. The availability of such inexpensive videography equipment for the everyday consumer is rapidly changing the ways in which people interact with video in their lives, especially through image, video, blog, or social network hosting/sharing sites such as Flickr, YouTube, Blogger, MySpace, and Ning. However, the implementation of new technologies in science teacher education often trails behind technology use in the consumer market. This lag-time between when new equipment, software programs, and applications of media become available and when these technologies are introduced into K—12 classrooms can be attributed to policies that make access in K—12 schools complicated and also because of a considerable lack of professional development for current and future teachers on how to integrate technology in the classroom.

In a historical overview spanning nearly 40 years, Miriam Sherin (2004) argues that major advances in video implementation in teacher education programs have been driven by both technological innovations and prevailing theoretical frameworks in teacher education. Sherin cites the evolution of learning theories from primarily behaviorist models where teaching was viewed as a "well-defined activity consisting of a set of skills to be practiced and learned," to the growth of cognitive psychology models of learning to teach where "researchers and teacher educators began to focus more on the ways in which teachers *think* rather than the ways in which teachers *behave*" (p. 5). As a result of these theoretical shifts, Sherin notes that teaching began to be seen as a more complex activity, from which emerged the utilization of video to help novice teachers develop practical teaching knowledge by observing and analyzing the actions of veteran teachers. Early video use focused on reviewing episodes of microteaching or analyzing/coding of teacher actions in video (e.g., via the Flanders (1970) method) to identify, discuss, and emulate specific teaching actions characterized as behavioral aspects of classroom teaching practices. Notable among early research using video for strategy analysis was Russell Yeany's (1977, 1978) training of preservice science teachers to analyze and code videos of science teaching using observational guides to help new teachers gain awareness of different classroom teaching practices. Following this training, teachers would engage in peer-teaching of a science lesson that was designed to model some of the same practices identified via the strategy analysis training. These lessons were videotaped so that the teachers could self-analyze their lesson using the same strategy analysis techniques to determine how faithfully they had implemented the observed teaching practices.

This early approach to teacher training was grounded, as Sherin (2004) observed, in a behaviorist model of learning to teaching where students acquired specific skills to implement in classrooms. Behaviorist theories of learning tended to see teaching as a set of knowledge and practices that can be acquired and directly transferred to any classroom. Such theoretical perspectives were quite common in teacher education during the 1970s, as teaching was seen as a set of behaviors to be learned. Yeany's work on strategy analysis heavily influenced some of the early studies involving video as a means for modeling certain teaching strategies, such as student-centered activities, and became an impetus for other studies using video to examine the relationship between science teaching strategies and student engagement and achievement. For example, Linda DeTure (1979) employed video to analyze interaction patterns between teachers and students in science classrooms, and in particular she used video to capture classroom interactions and then used these data in her work as a teacher educator. DeTure's use of video as an ethnographic tool for capturing and analyzing classroom interactions was relatively novel in itself; however, she then re-purposed the video to model for preservice teachers the strategy of extending the "wait-time" after teachers ask questions of students before responding to, or calling on students to respond, as a way to promote increased dialogue among students.

In the 1980s, researchers began to use video not only as a means to conduct classroom research, but also to produce video cases to model teaching strategies for preservice teachers. Several researchers in the late 1970s and early 1980s were active in developing video cases of science teaching, which were shared with prospective teachers as a means to engage them in controlled teaching experiences where they analyzed video and teacher narratives in an effort to reflect on their own beliefs about science teaching. In the sections to follow, we expand on these ideas and trace the development of the ways in which video and multimedia are currently being utilized in science teacher education. In the next section, we detail the organization of our analytic process and describe our approach to examining the literature on video in teacher education.

A Layered Approach to Analysis

What we have learned and describe in this chapter emanates from an extensive review in which we conducted an interpretive, comparative analysis of the literature around general uses of video/multimedia in teacher education (Martin and Siry 2008). Given that our own research involves the creation and analysis of primary source video in K—12 science classes, the evidence we have collected results from a multimodal inquiry and synthesis of literature in the field of teacher education combined with findings from our own research. We focus our analyses on the science teacher education literature, presenting trends that can be considered in structuring experiences for teachers to interact with video and multimedia as they learn about teaching and learning science at a variety of levels, and we begin by describing how we identified research for the initial review and then present our analysis of the literature.

Literature Review Approach

Stemming from a review of over 100 publications from journals, book chapters, and books, we categorized and analyzed the different ways in which video has been utilized, in an attempt to characterize the uses and reported efficacy of video in teacher education. Our analysis included sources focused on video and multimedia usage in preservice and in-service education as well as for research purposes. In this chapter, we are considering both the use of video as well as multimedia programs that generally include video clips as one part of the media component. We use both terms within the chapter, but attempt to distinguish for the reader how video is utilized in each context. In our discussion of video, we use the term video in reference to recorded images and sound. When we make a distinction between videotape and digital video, it is to denote the method used to store and access recorded images and sound. Initially we conducted several levels of analyses of these literature to describe differences in the intended purpose of video implementation, and the targeted audience for the video usage. From the first level of analysis, we developed six categories of video implementation, including (1) video cases, (2) hypermedia/multimedia presentations of video, (3) video for self/individual analysis, (4) tools/programs for analyzing video, (5) video utilized in electronic portfolios, and (6) conferencing facilitated by virtual/video interaction.

Once we categorized the literature according to usage, a second level of analysis demonstrated that video has been utilized in teacher education programs for a variety of purposes. We identified four main reasons, including: (1) to demonstrate "best practices" of specific teaching strategies, (2) to document growth or development in teaching and learning practices as an evaluation of individuals and/or programs, (3) to promote reflective practices, and (4) to record classroom events for educational research. The findings that follow emerged from this categorization and analysis. This synthesis and review is by no means exhaustive of all the research being done in science teacher education with video technology, but is meant to provide readers with a historic overview of seminal earlier works, as well as an understanding of the emerging and innovative research using video in the field of science teacher education. The implications we outline provide suggestions as to the ways in which video and multimedia can be utilized by science teacher educators and researchers.

Video Implementation and Uses

Video Cases

Teacher educators often tout case methodology as a powerful tool for creating a bridge between theory and practice. The literature offers many instances of studies and descriptions of programs where teacher educators use pedagogical dilemmas, both in the form of written case as well as video case studies. Video cases take a variety of forms, including commercially made video as well as cases created by science teacher educators to represent what they consider to be exemplars of teaching and learning situations. Case method instruction offers pre- and in-service teachers with models of how to approach pedagogical dilemmas and is thought to help bring the complexities of classroom activities into focus by allowing teachers to connect the theories being discussed at the university with real-life scenarios from K—12 classrooms. Also of great importance, case methodology is cited as a cost-effective and logistical solution for circumventing issues related to field experiences – either not having time in program schedules for extended field placements or not having suitable placements for preservice teachers to experience classrooms where teachers enact "best practices." Although some researchers have raised questions about the efficacy of case methods (e.g., Copeland and Decker 1996 for a critical examination of video/case study), proponents of case methodology laud the potential to support the development of teachers to become reflective practitioners and be able to analyze classroom interactions effectively and develop decision-making skills.

Most of the research on case studies in teacher education has focused on the use of text-based cases (e.g., Koballa and Tippins 2004, for examples of analyses of text-based cases designed to promote reflection on learning to teach science). In addition to these text-based cases, there is currently a growing body of work using video and multimedia to develop case studies. James Watters and Carmel Diezmann's (2007) research provides a good example of how video cases are used with preservice teachers to depict teachers and students engaged in various science activities. Enriched by a suite of multimedia resources, Watters and Diezmann created video cases depicting teachers and students engaged in various science activities. Designed to "make visible" the pedagogical practices and assumptions of teachers and the actions of students, these cases were shown to teachers who were then asked to reflect upon the cases and real classroom interactions and consider how these experiences inform their own teaching. As a frame for promoting discussions among teachers as they analyze and reflect on the classrooms depicted in the video, many studies invoke the work of Donald Schön (1987). In their study, Watters and Diezmann noted the need to situate teacher learning in "real" contexts, citing Lee Shulman's (1992) research on the importance of providing preservice teachers with "images of the possible" and a need to support in-service teachers to develop pedagogical content knowledge to improve their science teaching.

Case studies have clearly become the primary use of video for many education programs, and this seems especially true in the areas of K—12 math and science teacher education. Researchers using video cases in science teacher preparation often cite the lack of classrooms that incorporate inquiry-based science teaching (e.g., Yung et al. 2007) and note that video case studies provide authentic examples of classroom practice that become accessible to wider audiences. Videos of classrooms can be broad based, as with the Third International Mathematics and Science Study (TIMSS), and its follow-up study (TIMSS-R), providing an opportunity to examine classrooms across the 41 countries that participated. In this sense, teachers can gain a window into classrooms from other cultures, and consider the similarities and differences in the teaching of science and math. Writing about the use of these videos for learning about teaching, James Stigler et al. (2000) present the use of a video survey, which combines video with large-scale probability sampling and suggest that such a hybrid approach provides a support for researchers, as well as an opportunity for incorporating analytic approaches of teaching into professional development.

Sandra Abell, Lynn Bryan, Maria Anderson, and Katherine Cennamo have been pioneers in the use of video cases in science teacher education (e.g., Abell and Cennamo 2004). Abell et al. (1998) suggest that video cases provide prospective teachers with "virtual worlds" within which one can think about science teaching and learning. Abell and her colleagues developed what they termed, "integrated media (videodiscs controlled by hypermedia) cases of elementary science classrooms' which they used in an elementary science teacher education program to promote a reflection orientation in their preservice population. This group designed several structured prompts to promote discussion and reflection among preservice science teachers around a shared experience of viewing the same video vignettes as part of the case studies (e.g., Abell and Cennamo 2004). This early work has been very influential on the work of other researchers as evidenced by the many times the studies have been cited by science teacher educators who use video in courses.

Other examples of uses of video case studies in science teacher preparation include the work of Larry Bencze and his colleagues (2003), who created a set of cases based on video from seven lessons. In this study, the use of video cases led to a contextual understanding of the issues in teaching a science and technology lesson to children, and the authors recommend cases of this type as a way to incorporate authentic science observations into teacher preparation and professional development. More recently, Benny Yung, and his colleagues (2007) conducted a study in which preservice science teachers in Hong Kong were asked to watch the same two videos of exemplary science teaching three times during one academic year. The researchers found that progressive viewing, analysis, and reflection on the same videos over a period of time provided a supportive structure from which to scaffold these novice teachers' evolving understandings of science teaching during their preservice education.

Today, there are many examples of video cases being utilized in teacher education (e.g., see Barnett 2006, for an example of a web-based professional development system for pre- and in-service science and math teachers using video cases to develop an appreciation for and understanding of inquiry-based teaching (http://ilf.crlt.indiana.edu/). In fact, reports on the development and challenges of implementation of video cases were the most common papers we were able to access for our review. Terri Kurz et al. (2004) provide a comprehensive review of challenges associated with creating video cases for preservice science teachers and discuss recommendations for other educators and researchers. Despite reported challenges, video cases have become a critical component of many multimedia resources now available for science teacher education, as we elaborate on in the following section.

Hypermedia/Multimedia Presentations of Video

In the late 1980s, advances in technology allowed digitized video segments to be "hyper" linked to text and graphics which could be accessed on the Internet or using programs, such as HyperCard. The ability to provide *hyper* links to additional materials, such as lesson plans, samples of student work, audio interviews, or photos of classroom activities, all offered teacher educators and researchers a means to provide a richer social context for their video cases of exemplary teaching practice. Due to the hyperlinking of additional materials to one central site, location, or text/image/video, this technology was initially called hypermedia, but is now most commonly referred to as multimedia. While the terms are often used interchangeably in the literature when referring to mixed media applications connected to a central component, we refer to all hyperlinked media as multimedia.

Multimedia technologies are generally more cost-effective to develop than analog videos, offer increased functionality for users, and due to web-accessibility these products can be utilized with a wide audience. As a result of these technological advances, the majority of publications in both the late 1990s and currently, examine the role of video cases within the context of various multimedia resources. Multimedia presentations of video for science teacher education generally include different web-based activities available in classrooms, including scientific visualizations, simulations, virtual reality, animations, video clips or still images, and distributed information sources (Bodzin and Cates 2003). Watters and Diezman (2007) report on the development and use of multimedia materials that demonstrate professional practices and their data support the value of multimedia material for explicitly representing particular parts of practice and providing a shared experience for discussion, debate, and reflection. They suggest that the use of such multimedia can improve the experiences of distance/on-line learners, enhance field experiences by illustrating authentic classroom science teaching for comparison and discussion, and result in an increased willingness among future teachers to adopt technology within their classrooms as a result of positive experiences interacting with technology as a "mind resource" in their own education (p. 369).

The Multimedia in Science & Technology (MUST)-project in the Netherlands combines interactive video linked to comments by teacher educators and prospective teachers, context description, curriculum and lesson plans, and justification for video cases focusing on outdoor activities in science education (Van den Berg et al. 2004). Another example of multimedia resources used in science teacher education includes materials from Knowledge Media Laboratory (KML) of the Carnegie Foundation where users can access a free web-based program called KEEP Toolkit, which enables K—12 teachers to share "snapshots of practice" from their own science classrooms which pre- and in-service teachers can both view. Described as a "living archive of practice," users can then engage in reflective analysis and interactive discourse with one another. Emily Van Zee and Deborah Roberts (2006) describe this project and provide an evaluative discussion as related to science teacher education. The Gallery of Teaching and Learning (http://www.cfkeep.org) provides a venue to view an exhibition of faculty, teacher, and student-developed studies in science and technology education. Reflecting a science teaching and content perspective, the eSTEP and Knowledge Web projects offer a digital library of video linked to a hypertext book. These programs provide pre- and in-service teachers a variety of content developed to offer windows into K—12 science classrooms that engage participants in design experiments structured to develop cognitive theory, sociocultural understandings about classrooms, and science pedagogical content knowledge (Derry et al. 2002).

The development of new software and video-web sharing sites that provide users the ability to edit existing archives of video or to edit and post their own video for discussion within a larger teacher education community is a significant trend to consider. Video annotation tools provide interesting possibilities for enabling individuals to capture and analyze video of personal teaching as well as review, analyze, and synthesize examples of their own teaching for viewing by others. In Peter Rich and Michael Hannafin's (2009) recent review of video annotation tools, they urge educational researchers to consider the potential of utilizing video analysis programs, such as Transana (www.transana.org), DIVER (diver.stanford.edu), and Constellations (orion.njit.edu) not only for their data-mining capabilities, but also as tools for analyzing instructional decision-making processes and participant interactions in classrooms. Additionally, they call for expanded research agendas to examine not only the utility of these tools for promoting reflection practice, but also the impact, effects, and risks associated with using these technologies in educational research. Roy Pea (2006) argues that ethical and legal restrictions preventing researchers from sharing original data sources for reanalysis by other researchers obscures connections between evidence and argument, impedes research, and as such, discourages researchers from utilizing video as data. Noting the proliferation of digital video recording in the contexts of social sciences research and learning technologies, Pea and Robb Lindgren (2008) call for the creation of *video collaboratories*, in which researchers from around the world and in differing disciplines would access virtual repositories with video files and associated metadata to develop a community to share "video data sets, metadata schemes, analysis tools, coding schemes, advice, and other resources, and build video analyses together, to advance the collective understanding of behaviors represented in digital video data" (p. 236).

Advances in video technologies such as these provide unique pathways for the educational community to engage in cutting-edge research on how people learn to teach. We have found that the majority of the information about these innovative projects and sites are not available as publications. That these technologies are available as free access websites expands opportunities for changing the roles and responsibilities of teachers in research. We discuss the issue of autonomous video use by science educators and researchers in greater detail in the following section.

Video Used for Self/Individual Analysis

Proponents of video usage in teacher education often reason that teaching occurs in isolation from peer support, and that sharing video of one's teaching with others offers an opportunity to not only see oneself in the act of teaching, but also provides a convenient "window into a classroom" where others can view and discuss the teaching and learning that has been documented. Video serves as a lasting record, which can be reviewed and analyzed over and over from different perspectives, with different people, and over long periods of time. Advances in technologies have now made it possible for teachers, students, and researchers to not only view video, but to also rewind, fast forward, and advance the video frame by frame to analyze classroom interactions. This can support careful consideration of participant actions and discourse around pedagogy and content, and provides a focus on interactions at the micro level. In this way, the use of video by classroom participants and researchers mediates becoming consciously aware of the unconscious practices that are not generally available to us when social life unfolds in real time. Indeed, watching oneself and other teachers has become common practice in teacher education and promises to become more so as video continues to be an important means of evaluation and instruction in education programs around the world.

The ability to digitize video has contributed to the most significant technological advancement shaping the way in which video is being utilized in education today. Sherin (2004) attributes current developments to the fact that now video can be explored in a nonlinear fashion, no longer restricting users to sequential viewing of recorded actions, but enabling viewers to move through time, rewind actions, and jump to different segments of recorded interactions. We have found that this change in user dynamic has not only influenced the ways in which educators and researchers have implemented video playback in teacher education programs, but that these advances have begun to shape theories of how people learn to teach using these technologies. Indeed, many of the papers published within the last 5 years have begun to consider not only *what* teachers are learning about teaching via multimedia interactions, but also *how* teachers are learning from these experiences. Researchers are beginning to raise both theoretical and methodological questions about how tasks should or could be scaffolded to support learning as users choose to move through these multimedia materials in unstructured, nonlinear pathways. Our review suggests that there is a growing shift away from using predeveloped video cases and supporting multimedia resources in teacher education towards involving teachers in the construction of their own video cases, either by editing pre-captured video of classrooms or by capturing and editing their own teaching for the purpose of critical reflection with others about how to improve science instruction.

Interesting examples of how teacher educators and researchers are introducing the concept of autonomy and videography in teacher education include utilizing programs that enable teachers to annotate, edit, and share video with others for the explicit purpose of constructing meaning from the perspective of the individual, to then be shared with a larger community of educators, both in face-to-face and on-line education courses, teacher-led professional development groups, and for educational research. One example, called *video clubs*, engages in-service teachers and a facilitator (often a university researcher) in regular school-based meetings to watch and discuss excerpts of one another's teaching. Researchers Elizabeth van Es and Miriam Sherin (2008) note that video clubs provide a forum for teachers to effectively discuss pedagogy, content knowledge, and student learning where video plays a pivotal role in providing a shared experience from which teachers frame discussions. Using desktop video editing software (e.g., iMovie), Randy Yerrick et al. (2005) found digital video editing an effective tool for helping promote reflection in preservice elementary science teachers. These researchers found that the cyclical process of engaging students in editing, producing, and sharing personal science teaching vignettes through digital video editing extended participant engagement with their own teaching, helping them to make “mature and insightful shifts in their thinking about science, teaching, and even their own science experiences as children” (p. 369).

Described by Linda Beardsley et al. (2006), VideoPaper is a presentation of text and video side-by-side, where authors annotate digital video and upload still images captured from video (e.g., offprints of facial expressions of students), scanned content (e.g., student work), or other digital images. VideoPaper allows users to choose to read text and play video as originally intended by the author of the content, or select to interact with the raw data (in the form of video, text analysis, etc.) as the reader chooses, without needing to advance through the material in a linear fashion. Used primarily with in-service teachers and in conjunction with educational researchers, VideoPaper is a good example of programs currently being developed and used to provide teachers with opportunities to perform research on their practice by choosing video episodes to (re)construct and (re)present for others in order to share their understanding of the moment (see http://vpb.concord.org/about/ to access VideoPaper Builder).

These are just three examples of some of the ways in which video can support pre- and in-service teachers to consider new aspects of their practice. By providing access to tools that allow for individual and shared editing, viewing, and discussion of classroom events captured on video, teachers and researchers are able to engage in more complex and innovative uses of video technologies to improve teaching and learning. As these technologies continue to evolve, they offer a more cost-efficient means for evaluating teaching practice via greater distances, and thus, reduce the need for on-site teacher supervisors and mentors. Examples of this trend include the utilization of video-mediated communication [VMC] by veteran teachers to supervise/mentor preservice teachers (Ardley 2009) and the utilization of video-enabled, web-based computer-mediated communication [CMC] for supervisors to provide feedback to prospective teachers while engaged in a teaching practicum course (Lee and Wu 2006). More and more districts and teacher education programs are beginning to implement video as a tool for conducting program and individual teacher performance assessments. In the following section, we discuss video in the context of the assessment and evaluation of teachers as well as explore implications for changing practices in educational research.

Video Utilized for Evaluative Analysis

There are a variety of ways that video recordings have been used for evaluative analysis in teacher education. One way is for video to be used by teachers as part of electronic portfolios to document individual growth and development for evaluation purposes. A study that documented the use of web-based portfolios by preservice elementary teachers found that the use of such portfolios supported teachers as they developed their understandings of the ways in which children learn science (Zembal-Sual et al. 2002). In this project, preservice teachers authored hypermedia as they constructed their own portfolios. This was based on the assumptions that a web-based portfolio can place more emphasis on the process of constructing a portfolio, rather than the product itself. Further, the authors suggest that it is a more effective way of documenting the complex nature of teaching and learning. As teachers created "multidimensional and interconnected representations of learning" (p. 289), the research considered the types of representations that teachers included as well as the ways in which the portfolios revealed their understandings of science teaching. This study revealed that the web-based portfolios were successful in supporting critical reflection, enabling preservice teachers to make connections between their course work and children's learning using a nonlinear approach to documenting learning. Furthermore, some states, as well as the National Board Certification program, are now requiring video as evidence of effective teaching to be submitted as part of certification or certificate renewal processes (Park and Oliver 2008).

A less common, but seemingly increasing, use of video in science teacher education is for program evaluation. A current study (Ruggirello and Pitts 2009) situated at the University of Pennsylvania's Science Teachers Institute (Penn STI), explores the ways in which the creation of electronic portfolios, which include videos, provides a medium to promote teacher reflection. It has been reported that through the use of video in e-portfolios, researchers were able to gain insights into participant practices, thus documenting and demonstrating evidence of growth in areas that met the goals of the University's teacher education program and evaluation. In the next section, we take up the issue of video usage in research in science teacher education, providing examples from the literature as well as examples for our own research.

Research

Our work using video in research and science teacher education is what prompted us to review the literature, and our experiences with video provided a lens to interpretation. Our approach to research on learning to teach science involves collaborating with pre- and in-service teachers and students to discuss and analyze shared classroom events as recorded on video. Thus, we use video to capture events in the classroom, and replay this video to reexamine moments in time and analyze classroom interactions. By working directly with teachers and students to examine video, we seek to develop a reflexivity that goes beyond reflecting on past events. In our research, reflexivity implies that participants are reflecting upon what occurred, from their own standpoints, with the explicit intention of considering ways to improve practices moving forward. In this way, video helps us to develop a polysemic approach to understanding teaching and learning.

From an analytic perspective, the uses of video with participants are vast. In addition to simply replaying classroom events (either events at which all were present or not), video can be used in ways that manipulate the perspectives of time. Video can be sped up or slowed down to examine particular features of classroom interactions, and gesture analysis can be added through successive offprints (e.g., see Roth 2005, p. 234, for examples of how to create gesture diagrams and offprints from captured video for empirical analyses). Further, video provides an innovative window from which to examine the role of emotions in the learning of science, and a variety of micro-analytic approaches have been utilized to examine the ways in which emotions mediate the teaching and learning of science. Examples include the analysis of prosodic features of participant voices, facial expressions, gestures, and body language (e.g., see Roth and Tobin 2010 for utilization of video and audio to identify aligned and misaligned prosodic episodes between teachers and students and their effect on conflict and solidarity in an urban science classroom). Consequently, the use of video can be a valuable tool for teachers and researchers as they investigate learning to teach science.

In Jennifer Adams' (2009) collaborative research with preservice urban teachers, participants work together in cogenerative dialogue groups to discuss their student teaching experiences. In the cogenerative dialogue groups they then share selected video vignettes from their host classrooms and co-analyze them during the research meetings. In this way, the preservice teachers, as research participants, have central roles in data collection and analysis. In our own experiences, as in Adams' work, the ability to replay classroom events with varying speeds allows a research group to focus on interactions and to examine moments that may have passed unnoticed in teaching, and provides a forum for individuals to share their classroom experiences with others. We have learned that if teachers are in control of the videoing, have a voice in what gets videoed, and how the video is viewed, edited and interpreted, then the process becomes more transparent, and is less anxiety-ridden.

Thus, collaborative research between teachers and researchers is one way to mediate the anxiety surrounding the use of video. Much of the research we have reviewed indicates that teachers benefit as practitioners and researchers with expanded access to forums where they experience autonomy with regards to the capture, editing, annotation, analysis, and (re)presentation of themselves in video that is used for educational research purposes. Advances in video technologies are expanding the roles that teachers and their students play in research, making it imperative that we recognize and pay attention to ethical concerns associated with classroom research. In the following sections, we begin to address some of these issues and raise questions for teacher educators and researchers to consider.

Challenges of Implementing New Technologies

Simply making technology available, such as placing computers in K—12 classrooms, does not typically enhance or transform classroom instruction, as the technology is likely to be utilized to support existing teaching practices (e.g., replacing "chalk and talk" lectures with PowerPoint enhanced "point and click" lectures). This includes both K—12 classrooms, as well as classrooms in teacher education programs, where research, such as that by Jon Pedersen and Randy Yerrick (2000), has shown implementation of changing video technologies also lags behind the consumer market. Based on results from a broad-scale survey, Pederson and Yerrick found that even while science teacher educators report they use technology themselves and think it is important for teaching science, the majority are not integrating technology into their instruction of future science teachers. Acknowledging the same disconnect in science teacher education and implementation of technology that other researchers have found in K—12 science classrooms, these researchers urge the science teacher education community to address the need to programmatically improve the preparation of future teachers by addressing this disparity of belief and practice in their own courses. Additionally, there have been instances of school policies that limit the technology that could be available to educators, like accessing the vast database available on video sharing sites, such as YouTube, which have been blocked by many public schools in the USA, the UK, and in some states in Australia, all of which cite concerns about inappropriate content on the website. Thus, preservice teachers are often not exposed to implementing innovative uses of video technologies in their preparation at the university level or in the classrooms in which they observe.

One possible reason science teacher educators may not be informing prospective and current science teachers how to implement technology for science instruction is that the publishing process for research papers takes a considerable amount of time, leading to publications about the uses of video technologies in teacher education lagging behind current cutting-edge trends in technology. For example, some of the most widely cited work on the use of video cases with preservice science teachers stems from a project beginning in the late 1980s and early 1990s, involving laserdiscs as the delivery format for viewing video cases of exemplary science teaching in an elementary science methods course (see Abell and Bryan 1997). At the time, this research was cutting edge, but the laserdisc, like VHS tapes and even CD-ROMs, have become virtual dinosaurs in the everyday lives of most students and teachers. In a more recent publication referencing the papers from 1997 and 1998 (Abell and Cennamo 2004), this research group indicated they have transferred the video cases from the laserdisc format to an updated web-based media site, but this work raises important considerations about the timeliness of publication and implementation of these technologies. One of the dilemmas we have found in the literature is that the information published about advances in utilization of video technologies in teacher education is far behind the general consumer's use of video, but the use of video technologies in teacher education is also out of sync with current advances in video technology. With the proliferation of web-based journals, perhaps there will now emerge additional reliable, valued means of disseminating research and information about advances in technology and potential impact on practice, which can be accessed sooner than traditional journal publications.

In addition to the issue of lag-time in new practices and technological advances, the majority of the publications we have analyzed are mostly descriptive in nature, focusing often on the process of developing a video/multimedia product to be used with pre- and in-service teachers or describing the implementation of a product with a sample population of teachers. In other words, while many authors have exciting new uses for video or multimedia, there is not much evidence as to what purposes these tools actually serve toward learning about science teaching. Many of the studies we reviewed, including those more than 30 years old, highlighted the same problem. For example, Fuller and Manning in their *Review of Educational* Research publication from 1973, chided authors for commonly providing descriptive accounts of ways in which they used video in their teaching, evaluation, and supervision, and research without sufficiently explaining theoretical and methodologically sound frameworks for data collection and analysis for the widespread application of video in teacher education (e.g., for extensive review and critique of early literature focused on "confrontation of self" through video playback, see Fuller and Manning, 1973). Thus, while there has been much innovative work done on developing and implementing specific materials, there is a need for researchers to also consider the ways in which people are interacting with video-based media, and to ground their work in theoretically and methodologically sound ways that reflect the researchers' perspectives and foundations.

Implications

Our analysis for this chapter has focused on how video and multimedia have been utilized specifically in the education of science teachers and we have offered examples of some of the contexts in which teacher educators and researchers have implemented these tools in the education of K—12 teachers. We have drawn attention to advances in video and multimedia technologies which continue to offer new potential in the realms of educational research and teacher preparation through the adaptation of video technologies for learning about and improving teaching. We have found a wide range of rationales for using video in teacher education, and found that research studies and professional development efforts utilizing video vary considerably, depending on the ways that video has been adapted for particular instructional or research goals of a specific program or study. In this way, we can be flexible in our uses of video while continuing to expand our understanding of how these technologies inform teaching and learning.

While we have found much literature around the development and implementation of specific video technologies, there is not much that has been published about how these technologies can mediate the teaching and learning of science. We are left with important questions to consider in the field of science teacher education. In particular, we wonder, what role can science teacher educators play in transforming science teaching practices through video technology implementation? Further, we ask, how can/do pre- and in-service teachers use video technologies to reflect upon their own science teaching and science learning experiences?

As more educators introduce video and multimedia resources as teaching tools into their courses and as more programs require electronic portfolios with integrated video analysis, there are implications for what is being asked of teachers and how video/analysis and supporting resources are being used. Additionally, on-line teacher education programs are proliferating as communities become more multimedia savvy and as education programs extend their services to educate teachers in remote areas or those with few resources. The expansion of on-line education options greatly increases educational opportunities for people around the world. While this may be a positive direction for education, it raises many new questions about the role of technology in teacher education. As researchers, we must question how to effectively integrate video/multimedia in these programs to promote teacher reflection and we need to develop new evaluation methods to assess the effectiveness of these new learning technologies. Research also needs to be done to determine how to make these programs more effective given that the future will continue to include many new technological advances in video and other areas, and educators at all levels need to continue to engage in "cutting-edge" research to meet the needs of future teachers and learners.

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Chapter 30
Professional Knowledge of Science Teachers

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Nathaniel Gage (1964) points out that teaching, like all other classroom activities, embraces far too many different kinds of processes, behaviors, or interactions for it to be described by a single theory. Even then he was suggesting that the concept of teaching and learning should be analyzed in the light of teachers' types of activities, educational objectives, and learning theories. Therefore, estimating the quality of a lesson is inseparably combined with teachers' professional activities in the classroom and it can, for example, be controlled by assessing students' learning outcomes at the cognitive and emotional levels. As a consequence, research on teaching and learning at school deals with the question of the quality of instruction from at least three different angles, which include certain perspectives and facets of teachers' personalities, their professional knowledge, and its application under classroom conditions. During the last 40 years, research on the professional knowledge of teachers has been mainly conducted using three paradigms: the teacher personality paradigm; the process-product paradigm; and the expert paradigm. In the following section, these paradigms and their relations to the professional knowledge of teachers are discussed.

Jacob Getzels and Philip Jackson (1970) investigated the extent to which teachers' personalities influence their students' learning outcomes. Personality may be viewed as a dynamic organization of those traits and characteristic patterns of

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behavior that are unique to an individual (Callahan 1966). The major features of effective teaching identified by Milton Hildebrand and Robert Wilson (1970) are: (1) clarity of organization, interpretation, and explanation; (2) encouragement of class discussion and the presentation of diverse points of view; (3) stimulation of students' interests, motivation, and thinking; (4) manifestation of attentiveness to and interest in students; and (5), manifestation of enthusiasm. In addition, a large number of different characteristics of teachers' personality were also identified in many studies but these characteristics turned out to be not useful to effective teaching. All the profiles relating to personality turned out to be partly trivial or too complex to investigate, and consistent effects of at least some features of the teacher's personality on students' behaviors, emotions, and learning outcome in classrooms were not found (Bromme 1997).

Following the process-product paradigm, some aspects of teaching and learning have been studied and found to be highly correlated with certain facets of students' performance, interests, and attitudes. More than thirty years ago, Barak Rosenshine (1979) summarized corresponding aspects of the quality of instruction from this perspective using the notion of direct instruction which is taken as a reference in many studies to this day (see also Brophy 2000; Weinert et al. 1989). Rosenshine concludes that most researchers agreed time on task, having explicit goals, organizing lesson content using reasonable units, offering sufficient training opportunities, and controlling students' learning progress, are the main characteristics of quality of instruction. Most of the characteristics of direct instruction are related to the teacher's ability to act under classroom conditions. According to Jacob Cohen (1988), medium effect sizes could be identified in those studies on classroom conditions (Wise and Okey 1983; Fraser et al. 1987). In different but comparable studies, correlations could be found among the mentioned unique features of the quality of instruction by developing more or less elaborated structured models. Thus, Marten Clausen et al. (2003) developed a systematic model of quality of instruction and Andreas Helmke (2003) published a framework called the opportunity-use model, characterizing some aspects of the relations between teaching and learning in a classroom. Recently developed models and approaches to improve the quality of instruction also include features of teachers' professional knowledge as a main element.

As a synthesis of the personality paradigm and the process-product paradigm, Rainer Bromme (2003) proposed analyzing lessons of teachers identified as successful. To describe these teachers' expertise, a model was used by referring to Lee Shulman's (1986, 1987) notion of teachers' professional knowledge. To distinguish between experts and novices, teachers are selected by measuring variables like the students' improvement in learning or the teachers' professional experience (Bromme and Dobslaw 2003). In addition, there are some studies on the correlation of subjective theories, or teachers' beliefs, as they are called today, and teachers' classroom activities (e.g., Peterson et al. 1989; Staub and Stern 2002) without assessing students' learning outcomes. There is also a study on the relation between professional knowledge and students' performance measured with the PISA tests for mathematics but without investigation of classroom activities (Baumert et al. 2010).

Professional Knowledge in General

As mentioned, professional knowledge of teachers, discussed as an essential precondition for successful teaching, is therefore linked to the discussion about teachers' competencies in general and standards for teacher education in particular. Models of professional knowledge have been more or less explicitly included in all attempts to describe the quality of instruction. In parallel with these developments, the standards of teacher education have been developed and summarized, for example, in a report of the AERA Panel on Research and Teacher Education (Cochran-Smith and Zeichner 2005) and in the program of the National Academy of Education (NBPTS; Darling-Hammond and Bransford 2005; Oser and Oelkers 2001), to give perspectives on and to analyze their effectiveness in teacher education. All these proposals are normative and describe a set of competencies considered as general preconditions for good teaching. Walter Herzog (2005) points out that there is only a poor connection between those competencies and theories; that is, the choice of competencies is characterized as open and subject to change. James Calderhead (1996) describes six elements of the teacher planning process: planning occurs differently for different time spans (Shavelson and Stern 1981) and units (Clark and Peterson 1986); planning is mostly informal; planning is creative; planning is based on knowledge of subject matter, classroom activities, children, teaching, school conventions, and so on (Clark and Yinger 1987); planning allows for flexibility; and, planning occurs within a practical and ideological context. The line of the development of a theory on teachers' professional knowledge to act under classroom conditions can be tracked from Lee Shulman (1998) to Franz Weinert (2001), and to the five core propositions of the NBPTS (2002). These propositions are: (1) teachers are committed to students and their learning; (2) teachers know the subjects they teach and how to teach those subjects to students; (3) teachers are responsible for managing and monitoring student learning; (4) teachers think systematically about their practice and learn from experience; and (5) teachers are members of learning communities. Symptomatically, all those general attempts do not explicitly contain statements on subject-specific pedagogical competences, which are in non-English-speaking countries called *didactic of the subject* and described as strategies of teaching the content of a certain subject. Even proposition (2), only refers to knowledge about subject matter and not explicitly to knowledge of how to reduce or reconstruct content knowledge for certain situations in the process of teaching and learning under classroom conditions.

To describe the effect of teachers' professional knowledge, most recent research projects use distal indicators like state certifications or marks to correlate with indicators of the quality of instruction or students' learning outcomes. For example, Suzanne Wilson and Peter Youngs (2005) report positive correlations between teachers' certificates and their general pedagogical knowledge and students' increase of knowledge in a certain subject. Most of those studies contain the inconsistency of using general pedagogical knowledge as a measure but they mostly do not consider the conditions of lessons of specific subjects. Therefore, Marylin Cochran-Smith and Ken Zeichner (2005) emphasized that it is now necessary to develop measures and variables to reliably and validly capture data on professional knowledge in all facets, to correlate with learning outcomes regarding different subjects. According to Shulman (1986, 1987), professional knowledge can be divided into seven categories that seem to influence teachers' behavior in the classroom: (1) content knowledge; (2) curricular knowledge; (3) pedagogical content knowledge; (4) general pedagogical knowledge; (5) knowledge of learners and their characteristics; (6) knowledge of educational contexts; and (7), knowledge of educational ends, purposes, and values. In recent research, reduced models of Shulman's concept are mainly applied using only content knowledge (CK), pedagogical content knowledge (PCK), and pedagogical knowledge (PK) (Baumert et al. 2010).

In some models, subject matter is included in PCK (Fernandez-Balboa and Stiehl 1995; Marks 1990). In most investigations, different test instruments are applied to assess the three dimensions of professional knowledge independently without integrating them. For example, content knowledge and alternative concepts are analyzed from different perspectives (e.g., Harlen 1997; van Driel and Verloop 1999). Marissa Rollnick et al. (2008) deal with relations between pedagogical content knowledge and subject-matter knowledge, or Pernilla Nilsson's (2008) study reveals pedagogical content knowledge as an amalgam of subject-matter knowledge, contextual knowledge, and pedagogical knowledge. Up to now, a connection between CK and teaching practice has been analyzed mainly using case studies, based on which it is generally agreed that positive connections exist between CK and supportive teaching, but such connections are only restricted to the cases being studied (Gess-Newsome and Lederman 1995; Newton and Newton 2001). Pedagogical content knowledge as transformation of subject-matter knowledge into forms accessible to the students (Geddis 1993) has also been described using different theoretical frames, for example, by Onno de Jong and Jan van Driel (2001), and analyzed in greater detail regarding different facets like concepts on teaching and learning, various subjective theories, beliefs, and attitudes by others (see also Loughran et al. 2001; Porlán et al. 2004). Finally, pedagogical knowledge – as knowledge of teaching, learning, instruction, classroom-management, goals of Bildung – is seen to be subject-independent and general. Facets of PK regarding science teaching were investigated by David Treagust (1991) and Anat Zohar (1999) also by means of case studies. A model for professional knowledge based on the reduced version of Shulman's concept already exists for mathematics teachers, and at least CK and PCK and interdependencies are assessed by correlating CK and PCK with students' performance in large-scale assessments (Baumert et al. 2010; Organisation for Economic and Cultural Development (OECD) 2003). High CK and PCK of teachers of mathematics are seen as a necessary precondition for good performance of their students but only if the lessons are cognitively demanding. Up to now, the influence of PK on teaching and learning or quality of instruction has not been connected with students' competencies regarding science subjects. In addition, effects on motivation and interest are not sufficiently investigated.

According to Jürgen Seifried and Detlef Sembill (2005), learning has to be seen as a complex process not only focusing on cognitive performance but also on emotional, motivational, and interest-related elements (Kunter 2005). Therefore, besides professional knowledge of teachers, students' cognitive development and lesson activities, motivation, and interest of students and teachers should be considered when analyzing teaching and learning at school (Weinert 2001).

Professional Knowledge of Science Teachers

As already pointed out, the debate about teacher knowledge in science education mainly highlights the three areas: content knowledge (Krauss et al. 2004), pedagogical content knowledge (Baumert et al. 2010), and pedagogical knowledge (Bromme 1997, 2001), as being relevant for teaching and research (Wilson and Floden 2003). Therefore, standards for professional knowledge of teachers describe mainly expected competencies in those dimensions. Like the standards for student education and those for teacher education, all standards contain goals of a society for certain subjects in general (Oser and Oelkers 2001; NBPTS 2002), and the specific biology, chemistry, and physics standards, respectively (Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland [Secretary of the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany] 2005a, b, c), are necessarily normative (Klauer and Leutner 2007) but can be used for developing and empirically validating models to measure teachers' competencies (see Kauertz et al. in this handbook). In a cyclical process, on the basis of the results of student performance in respective tests, the underlying standards can be adapted to develop the standards for professional knowledge of teachers. In addition, establishing a correlation between professional knowledge, lesson activities and students' learning outcomes also contributes to modeling the quality of instruction. In a first attempt, the notion of professional knowledge refers to all kinds of theoretical knowledge learned during teacher education but also skills as a result of systematic in-service teacher training and teaching practice (Clandinin and Connelly 1995). Furthermore, personal characteristics, like attitudes, beliefs, and emotions, are also seen as elements or correlates of professional knowledge (Barnett and Hodson 2001; Moallem and Moallem 1998). Therefore, the professional knowledge of teachers is more than a fixed taxonomy of well-defined elements of knowledge clearly distinguishable and applicable to all possible situations in the classroom. But, not all knowledge of a teacher is unrestrictedly relevant for action because only some parts are applicable to regulating classroom teaching activities (Dann 1994; Fischler et al. 2002). With a model of instructional quality that takes into account not only instructional characteristics and their influence on outcome criteria but also framework conditions on classroom, school, and system levels, the gap between normative approaches in teacher education programs and process-product approaches, as stated by Barak Rosenshine and Norma Furst (1973), can be closed.

Content Knowledge

Content knowledge is seen as a necessary precondition for successful teaching (Ball et al. 2001; Shulman 1986, 1987). Nevertheless, most empirical research on instruction did not show this relationship, which may be due to the fact that pedagogy cannot be used to investigate the influence of teachers' content knowledge on instruction or even students' learning outcomes. Furthermore, difficulties with developing applicable test instruments for assessing teachers' content knowledge and their willingness to take part in these assessments lead to an unsatisfying quality of tests. Instead, content knowledge is often operationalized indirectly using teachers' certifications, their marks on reports or the number of seminars completed successfully by them. In contrast, Jürgen Baumert et al. (2010) defined and analyzed four different kinds of content knowledge: academic research knowledge, a profound mathematical understanding of school knowledge, school knowledge after some teaching experience, and the everyday mathematical knowledge of adults, which are available already after having passed some time teaching at school. Within the COACTIV-study, teachers' mathematical content knowledge is assessed immediately and mathematical content knowledge of teachers is understood as background knowledge of school content (Brunner et al. 2006a). Successful teaching is dependent on the depth of the teachers' exploration of lesson content including the structure of the content and theoretical modeling (van Driel and Verloop 1999). Deborah Ball et al. (2001) distinguished between this kind of background knowledge from university knowledge and considered these respectively as common knowledge of content and specialized knowledge of content, although they were not able to identify the postulated parts of their model by means of factor analysis (Hill et al. 2004). The results of the COACTIV-study showed high correlations between test results of the German students in the PISA 2003 study (OECD 2003) and their teachers' PCK and CK as well as strong connections between CK and PCK. CK was also found to be a necessary but insufficient precondition for PCK.

Pedagogical Content Knowledge

In contrast to CK, PCK represents knowledge that enables teachers to provide opportunities for students to learn certain content. Shulman (1987) describes PCK as a special amalgam of content and pedagogy that corresponds to a fusion of CK and PK. Accordingly, it seems difficult to distinguish the three kinds of knowledge: CK, PCK, and PK. Jan van Driel et al. (1998), and Soonhye Park and Steve Oliver (2007) combine different attempts for describing PCK regarding science instruction; and van Driel et al. (2002) agree on knowledge about learning processes, students' concepts, teaching strategies, and forms of presentation as central elements of PCK. Ineke Henze et al. (2008) use similar facets for describing PCK but reveal two qualitatively different types of PCK. Stefan Krauss et al. (2004) add a new facet by differentiating between teaching mathematical content, students' cognition regarding mathematics and the cognitive potential of mathematics tasks to represent all three sides of the didactic triangle: (1) the teachers and their subject-specific interventions, (2) the students and their subject-specific concepts, and (3) the subject matter with a certain cognitive potential (Cohn and Terfurth 1997). Knowledge on all three aspects is understood as a requirement for the creation of learning opportunities which allow students to be cognitively activated and thus to support their learning as far as possible. An adequate cognitive activation of students leads to an active use of learning opportunities and therewith to successful learning (Brunner et al. 2006b). Therefore, an adequate level of the teacher's or the task's requirement is indispensable. Already Lev S. Vygotsky's (1987) notion of the zone of proximal development has pointed out that cognitive activation of students should demand adequately but not to overtax their ability. Therefore, cognitive activation should consider pre-knowledge and so-called misconceptions as well as conceptual change as teaching strategies, which are seen especially as being necessary for learning sciences (Duit et al. 2007; Treagust and Duit 2008). Eunmi Lee and Julie Luft (2008) explored a PCK model consisting of seven aspects and suggested that knowledge of resources should be explored to determine whether it should be considered a component of PCK. Rainer Wackermann et al. (2008, 2009) report effects of an intervention to support teachers' ability to organize problem solving, learning by experience, and concept development in physics lessons using video analysis, test medium effect sizes, and acceptable correlations between the an appropriate structure of the lesson and students' motivation and interest. In addition, some important qualitative features, like the complexity of the levels of teachers' questions and the levels of their students' responses, could be linked to the lesson structure as well as teachers' self-reported experience in pacing and monitoring processes of the analyzed lessons.

Viewing PCK from a meta-level and using it as a heuristic device, John Loughran et al. (2008) refer to positive effects on student-teachers preparing lessons by using the Content Representation (CoRe) and Pedagogical and Professional-experience Repertoire (PaP-eR) for teacher training. Jürgen Baumert et al. (2010) report PCK and CK as separate factors as a result of a factor analysis but also an increasing integration of both constructs with increasing expertise. PCK itself shows a positive correlation to an effective instruction and students' achievement (Ball et al. 2005; Brunner et al. 2006b). General quality criteria that account for effective instruction have already been identified (Fraser et al. 1987; Wang et al. 1993). It is expected, however, that these general quality criteria must be complemented by subject-specific criteria (Helmke 2007). Sandra Abell (2007) summarizes the research perspective regarding CK and PCK as follows:

> The research in both SMK [CK] and PCK has predominantly been at the level of description. In the current area of standards-based education and accountability for student learning, science education researchers should make more efforts to connect what we know about how teachers bring to bear on science teaching, we know little about how teacher knowledge affects students. Answering this question will require more work in classroom settings of all kinds (…) and more complex research designs. The ultimate goal for science teacher knowledge research must not only be to understand teacher knowledge, but also to improve practice, thereby improving student learning. (p. 1134)

Accordingly, some of the recent case studies are describing science teachers' PCK qualitatively as being oriented to modeling content when talking about teaching the solar system (Henze et al. 2008). Lee and Luft (2008) also describe PCK of four teachers using semi-structured interviews. They found seven components of PCK: knowledge of science, goals of students, curriculum, organization, teaching, assessment, and resources. Again in a case study (but as an intervention), John Loughran et al. (2008) investigated the influence of an explicit teaching of elements of PCK to some preservice science teachers. As case studies with only small samples and descriptive attempts, most do not provide generalizable results but generate a picture of what can be expected when teaching PCK to science teachers. Up to now PCK is rarely measured directly using valid test instruments. One reason may be that PCK mostly refers to specific situations and proofs of the effectiveness of certain measures are difficult to carry out. For a detailed overview on PCK in science education see Julie Gess-Newsome and Norman Lederman (1999).

Pedagogical Knowledge

According to Shulman (1986), pedagogical knowledge includes knowledge of general principles of classroom organization and management. In more detail, Krauss et al. (2008) describe it as declarative and procedural knowledge to facilitate a trouble-free and effective course of a lesson and to establish a social climate supportive for learning which is tightly connected with knowledge about measures and strategies of class guidance as well as to effectively use the available learning time (Seidel and Shavelson 2007; Wang et al. 1993). Alexander Renkl (2008) summarizes effective class guidance as: (1) establishing an efficient system of rules, (2) avoiding no-load operation phases, (3) controlling disturbances, (4) outsourcing non-instruction activities, (5) consequent flow of lessons, and (6) clarity and adequate requirement levels. These principles include strategies to prevent disturbances in the classroom as well as corrective activities when disturbances occur but Thomas Good and Jere Brophy (1997), and Jacob Kounin (1976) attach a stronger effect to prevention. Pamela Grossmann (1990) and Shirley Magnusson et al. (1999) add also knowledge on general principles of instruction, learning processes, and personal characters relevant for learning and on teaching goals. Knowledge on general principles of instruction includes knowledge on numerous instruction forms that can use teaching methods regarding curricular content and teaching goals (Kunter et al. 2005; Seidel and Shavelson 2007) and adequate characteristics of the learner (Brophy 2000; Klauer and Leutner 2007). Knowledge on learning processes covers knowledge on different learning theories and its applicability in different situations (Blömeke et al. 2008). Knowledge about teaching goals, learning processes, and principles of instruction are seen as a necessary precondition for adequate cognitive activation (Kunter et al. 2006).

Because PK does not refer to a subject, it is seen as a general precondition for a high quality of instruction. Focusing not only on declarative but also on procedural knowledge PK includes knowledge on instructional measures and strategies and the conditions of their effective use under classroom conditions. Thus, PK can be seen as a necessary but not sufficient precondition to use CK and PCK for enhancing subject-specific learning processes.

Conclusion

Research on professional knowledge of teachers and its consequences for teaching and learning science have not been sufficiently developed. There are some well-established attempts in research on pedagogy describing PK but the relation between PK and subject matter, its structure, its transformation and operationalization for classroom conditions are not well known and only poorly investigated. Most of the research on CK and PCK, which are the most important facets of professional knowledge regarding science education (didactics of science or didactics of the different science subjects), still remains on a descriptive level. Moreover, recently conducted studies do not sufficiently refer to each other which lead to a deficit regarding reliability and validity of their results. Studies and models are needed that consider a combination of at least three main components of professional knowledge – CK, PCK, and PK and its correlations to student learning – and, most importantly, their effects on instruction to draw conclusions for teacher education and to develop quality of science instruction. Therefore, more studies are needed that investigate the correlation between variances of teachers' professional knowledge, and quality features of classroom interactions and of student learning outcomes in different subjects to find subject-dependent differences but also common features of professional knowledge and to connect teachers knowledge, teaching and learning processes, and students' knowledge and competences.

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Chapter 31
Science Teaching Efficacy Beliefs

Jale Cakiroglu, Yesim Capa-Aydin, and Anita Woolfolk Hoy

During the last few decades, educators have placed increasing emphasis on the scientific literacy in science education programs. Scientific literacy is based on a premise that all students should have the opportunity to learn and do science. In an effort to better prepare students in science, the science teacher is considered one of the most influential factors in increasing the quality of students' learning processes and outcomes. However, previous studies have indicated that many preservice and in-service teachers demonstrate a low confidence in their abilities to teach science and help students learn. Teachers who do not believe in their ability to teach science effectively, that is, teachers with low science teaching efficacy beliefs might avoid teaching difficult concepts in science or tend to spend less instructional time on science. For that reason, efficacy beliefs are one of the most powerful variables predicting both teachers' behaviors in science classrooms and student achievement in science.

The chapter begins with the theoretical foundation of self-efficacy, including origins, definition, and distinctive features of self-efficacy beliefs. Then we provide a brief explanation of teachers' sense of efficacy, including its conceptual framework and critical measurement issues. Next we focus on science teaching efficacy beliefs by summarizing major findings. Finally, we propose an agenda for future research.

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Meaning of Perceived Self-efficacy

Self-efficacy, which stands at the core of social cognitive theory, has generated a growing body of literature in psychology, medicine, education, and business administration since the publication of Albert Bandura's (1977) article Self-efficacy: Toward Unifying Theory of Behavior Change. Perceived self-efficacy refers to personal beliefs about one's capabilities to perform actions at designated levels (Bandura 1997). Self-efficacy beliefs can influence human functioning in numerous ways. They "influence the courses of action people choose to pursue, how much effort they put forth in given endeavors, how long they will persevere in the face of obstacles and failures, their resilience to adversity (Bandura 1997, p. 3). These subsequent performances are influenced by self-efficacy, whereas the self-efficacy beliefs are affected and altered in turn by how individuals interpret the results of their performance attainments (Pajares 1996).

The definition of self-efficacy is sometimes clouded by similar or related constructs such as self-concept, self-esteem, and locus of control. However, Bandura (1997) points out that although all other self-constructs are self-referential, self-efficacy is clearly different from each of them in that self-efficacy involves judgments of capabilities specific to a particular task. On the other hand, self-concept is a more global construct that contains many perceptions about the self, including self-efficacy. Self-esteem refers to perceptions of self-worth and does not include judgments of capabilities. There is no preset relationship between individuals' beliefs about their capabilities and whether they like or dislike themselves. For example, a man may judge himself as inefficacious in a given activity but not suffer any loss of self-esteem.

Although self-efficacy and locus of control often are viewed as the same construct, they correspond to entirely different phenomena (Bandura 1997). Originally developed under the umbrella of Julian Rotter's (1966) social learning theory, the locus of control construct refers to the degree to which an individual believes the occurrence of reinforcement is contingent on his or her own behavior as opposed to under the control of others. The factors involved with reinforcement expectancy are labeled internal and external control, respectively.

Bandura (1997) stated that locus of control is an outcome expectancy that could be defined as "a person's estimate that a given behavior will lead to certain outcomes" (p. 193). High locus of control does not necessarily indicate a sense of efficacy. For example, students may believe that high academic grades are entirely dependent on their performance (high locus of control), but feel hopeless because they believe they lack the skills to produce those superior academic performances (low self-efficacy).

Although other self-referential constructs may be more global (e.g., self-esteem, self-concept), self-efficacy is defined and measured as specific to behaviors in specific contexts or situations (Bandura 1997). Therefore, Bandura (1997) cautioned researchers assessing self-efficacy beliefs that they should use assessments that correspond to the specific task and the domain of functioning being analyzed. Otherwise, the resulting omnibus-type instrument would not only create problems of prediction, but also be unclear about what is being assessed.

Teachers' Self-efficacy Beliefs

Considering the task-specific nature of self-efficacy, Megan Tschannen-Moran et al. (1998) defined teacher self-efficacy as "teacher's belief in his or her own capability to organize and execute courses of action required to successfully accomplish a specific teaching task in a particular context" (p. 233). In their review paper, Tschannen-Moran et al. proposed a model suggesting that teacher self-efficacy is produced as a result of the interaction between analysis of teaching task in context and analysis of personal teaching capabilities. The resulting efficacy beliefs influence the teachers' professional goals, their effort expenditure, and their resilience when faced with difficulties.

The model also refers to the sources of efficacy information described by Bandura (1997): mastery experience, vicarious experience, social persuasion, and physiological states. Among these four sources of information, Bandura proposed that enactive mastery is the most influential source. A sense of efficacy to teach is enhanced when accomplishments are present in a person's history of teaching and particularly when these past successes are attributed to the individual's own efforts and abilities. Opportunities to observe a model's (colleague or mentor) accomplishments might be a source of vicarious experience that supports the efficacy judgments. Social (or verbal) persuasion refers to the specific positive talk about teaching performance from an administrator, colleague, mentor, or a student. Finally, physiological or affective reactions to a teaching task also add to the efficacy information, depending on how the arousal is interpreted. For example, if seen as anxiety, the arousal may lower efficacy expectation, whereas interpretations of excitement and readiness may raise efficacy expectations. These four sources of efficacy information are cognitively processed, that is, they are "selected, weighted, and integrated into self-efficacy judgments" (Bandura 1997, p. 79).

This process of selecting and weighting efficacy information differs for each individual as different factors may influence each person. Elizabeth Labone (2004) proposed that factors such as preexisting self-schema, task difficulty, and effort invested may influence the extent to which enactive mastery would enhance efficacy judgments. The cognitive process is considered as essential in the Tschannen-Moran et al. (1998) model because such processing will impact how the analysis of teaching task and personal competence interact with each other to form future efficacy beliefs.

Measurement of Teachers' Self-efficacy Beliefs

Two theoretical frames have shaped the measurement of teachers' sense of efficacy, Rotter's locus of control and Bandura's self-efficacy theory.

Rotter

Under the influence of Rotter's article published in 1966, the RAND Corporation included two efficacy items in their examination of teacher characteristics and student learning (Armor et al. 1976). Those researchers defined teacher efficacy as "the extent to which the teacher believes that he or she has the capacity to affect student performance" (McLaughlin and Marsh 1978, p. 84). In these studies, teachers were asked to respond to the two 5-point Likert-type items. Two items used to measure teacher efficacy were designed to measure the degree to which teachers consider environmental (external) factors as overwhelming any power that they can exert in schools or accept personal (internal) responsibility for what happens to them (Guskey and Passaro 1994). See Table 31.1 for further information. After this, other instruments with more items were developed such as Responsibility for Student Achievement (Guskey 1981), Teacher Locus of Control (Rose and Medway 1981), and The Webb scale (Ashton et al. 1982). Despite the important implications of these studies for teacher efficacy research, several researchers tried to expand the construct of teacher efficacy, and to develop longer and more reliable measures (Tschannen-Moran et al. 1998; Woolfolk Hoy et al. 2009).

Bandura

Patricia Ashton and Rod Webb (1986) expanded the Rand methodology by using Bandura's social cognitive learning theory, in which they made a distinction between outcome expectations and efficacy expectations. They believed that outcome expectation was assessed in the first Rand item, whereas efficacy expectation was captured in the second Rand item. Sherri Gibson and Myron Dembo (1984) developed a 30-item instrument called Teacher Efficacy Scale (TES) based on these two dimensions and later reduced it to 16 items. Through factor analysis of 208 elementary teachers' responses, they reported a 2-factor model that accounted for 28.8% of the total variance. Gibson and Dembo noted that Factor 1 represented a teacher's sense of personal teaching efficacy, and corresponded to Bandura's self-efficacy dimension. On the other hand, the second dimension stood for a teacher's sense of teaching efficacy, and corresponded to Bandura's outcome expectancy dimension. These two dimensions are now referred to as personal teaching efficacy (PTE) and general teaching efficacy (GTE), respectively. Gibson and Dembo presented alpha coefficients of 0.78 for PTE, and 0.75 for GTE. They recommended the use of the revised scale of 16 items for further research. Other instruments were adapted based on TES for specific subject matters. For example, Iris Riggs and Larry Enochs (1990) developed the Science Teaching Efficacy Belief Instrument (STEBI) to measure efficacy of science teaching and Larry Enochs et al. (2000) developed a similar instrument to measure efficacy of mathematics teaching.

John Ross (1998) reported that TES (or adaptations of TES) has been used in almost half of the studies performed up to 1998 to assess teacher efficacy. Despite its common use, there are both conceptual and statistical problems

Table 31.1 Measures of teacher self-efficacy

Instrument	Developers	Characteristic	Sample item
The RAND measure	Armor et al. (1976)	• Based on Rotter's theory • Two 5-point Likert type items	When it comes right down to it, a teacher really can't do much because most of a student's motivation and performance depends on his or her home environment. If I really try hard, I can get through to even the most difficult or unmotivated students.
Teacher Efficacy Scale	Gibson and Dembo (1984)	• Based on Bandura's theory • 30-item 6-point Likert scale • Two subscales: personal teaching efficacy (PTE) and general teaching efficacy (GTE)	I have enough training to deal with almost any learning problem. (PTE) Teachers are not a very powerful influence on student achievement when all factors are considered. (GTE)
Teachers' Sense of Efficacy Scale	Tschannen-Moran and Woolfolk Hoy (2001)	• Based on Bandura's theory • 24 items on a 9-point rating scale • Three subscales: efficacy for classroom management (CM), efficacy for instructional strategies (IS), and efficacy for student engagement (SE)	How much can you do to control disruptive behavior in the classroom? (CM) To what extent can you use a variety of assessment strategies? (IS) How much can you do to get students to believe they can do well in schoolwork? (SE)
Science Teaching Efficacy Belief Instrument A and B	Riggs and Enochs (1990) Enochs and Riggs (1990)	• Building on Gibson and Dembo's work • Two subscales: personal science teaching and science teaching outcome expectancy • STEBI-A: 25-item 5-point Likert scale • STEBI-B: 23-item	I am typically able to answer students' science questions. (STEBI-A) I will typically be able to answer students' science questions. (STEBI-B)
Self-Efficacy Beliefs about Equitable Science Teaching and Learning (SEBEST)	Ritter, Boone, and Rubba (2001)	• Based on STEBI • 34 items • Two subscales: personal efficacy (PE) and outcome expectancy (OE)	I will have the ability to help children from low socioeconomic backgrounds be successful in science. (PE) Good teaching cannot help children from low socioeconomic backgrounds achieve in science. (OE)

(Henson 2002; Tschannen-Moran et al. 1998). Some researchers stated their concerns particularly regarding the second factor, GTE (Guskey and Passaro 1994; Henson et al. 2001). For example, Thomas Guskey and Perry Passaro (1994) noticed that there are some biases in the wording of the items. Items measuring personal efficacy used the referent "I" and were positive; while items measuring teaching efficacy used "teachers" and were negative. For that reason, they changed the wording of the items in order to have balanced characteristics throughout the instrument (both positive and negative "I" items and both positive and negative "teachers" items).

When Guskey and Passaro administered this balanced scale, their results confirmed internal and external dimensions instead of personal and teaching efficacy dimensions. This categorization stems from locus of control theory rather than self-efficacy theory. Tschannen-Moran et al. (1998) discussed this theoretical distinction in detail, drawing upon the findings of the Guskey and Passaro study. Based on a reliability generalization study, Henson et al. (2001) concluded that use of the GTE subscale as a measure of teacher self-efficacy is questionable not only because of conceptual problems but also for measurement error problems. They suggested not using the GTE subscale.

Another commonly used teacher self-efficacy instrument is the Teachers' Sense of Efficacy Scale (TSES) developed by Tschannen-Moran and Woolfolk Hoy (2001). Taking Bandura's suggestions for constructing a self-efficacy scale (Bandura 2006) and using the Tschannen-Moran et al. model as a base, they developed an instrument assessing teachers' beliefs about their abilities to accomplish a variety of teaching tasks. After different validation studies, they generated a short form with 12 items and a long form with 24 items. Analyses of both forms indicated that the TSES could be accepted as a reliable and valid instrument for assessing the teacher efficacy construct. Both versions supported a 3-factor model with high subscale reliabilities. The factors were named efficacy for student engagement, efficacy for instructional strategies, and efficacy for classroom management. The authors argued that TSES could be used for assessment of either three domains of efficacy or of one generalized efficacy factor. The instrument was adapted to other languages such as Turkish (Capa et al. 2005), Greek, Korean (Klassen et al. 2009), and Chinese (Kennedy and Hui 2006).

Correlates of Teacher Self-efficacy Beliefs

Researchers have consistently found a strong relationship between teacher efficacy, teacher classroom behavior, and student achievement. For example, teachers with higher levels of self-efficacy tend to be open to new ideas, demonstrate greater levels of planning and enthusiasm, and are committed to their profession (Tschannen-Moran et al. 1998). Furthermore, higher levels of teacher self-efficacy have been related to positive classroom behavior management (Emmer and Hickman 1991). Further, efficacious teachers tended to be less critical of students when they made errors and worked longer with struggling students (Gibson and Dembo 1984).

In addition to the teacher variables, teacher efficacy is also linked to students' affective growth, student motivation, student self-esteem, and achievement (Midgley et al. 1989). Findings related to the relationship between teacher self-efficacy, and both teacher and student outcomes were discussed in Ross's (1998) article reviewing 88 teacher efficacy studies.

Science Teaching Efficacy Beliefs

Reinforcing Bandura's definition of self-efficacy as both subject-matter and context-specific construct, Riggs and Enochs (1990) developed the Science Teaching Efficacy Belief Instrument (STEBI) to measure efficacy of science teaching. Building on the Gibson and Dembo work, the authors identified two uncorrelated factors within STEBI, which they named personal science teaching efficacy (PSTE,13 items) and science teaching outcome expectancy (STOE, 12 items). The PSTE refers to teachers' belief in their ability to perform science teaching, whereas the STOE refers to the teachers' belief that effective science teaching can change student behaviors (Riggs and Enochs 1990). The original 25-item STEBI Form A was developed for in-service teachers in a 5-point Likert-response format (Riggs and Enochs 1990). Enochs and Riggs modified STEBI-A to a 23-item questionnaire suitable for preservice teachers (STEBI-B) by rewording the items to the future tense to reflect the anticipatory nature of preservice teachers.

By extending the level of specificity and using STEBI as a base, other subject-matter-specific instruments were developed including STEBI-CHEM (Rubeck and Enochs 1991) assessing chemistry teaching efficacy, the Environmental Education Efficacy Belief Instrument (EEEBI; Sia 1992) assessing efficacy beliefs in environmental education, and Self-efficacy Beliefs about Equitable Science Teaching (SEBEST; Ritter et al. 2001) assessing the self-efficacy beliefs of preservice elementary teachers with regard to science teaching and learning for diverse learners.

Studies with In-Service Teachers

Numerous studies investigated the construct of teacher efficacy and found that efficacious teachers tended to use activity-based science instruction and spent more class time teaching science (at the elementary level). They also used inquiry approaches, small-group learning, cooperative learning, and more student-centered instructional approaches. In contrast, teachers with low efficacy beliefs tended to utilize teacher-centered instructional methods and whole-class instructional techniques (Enochs and Riggs 1990). Considering the fact that student-centered approaches have gained importance in recent years in science education field, researchers have focused on how to improve teachers' self-efficacy beliefs. However, research findings are contradictory regarding the enhancement of different dimensions of STEBI. For example, some interventions have produced significant enhancement of teachers' PSTE, some in teachers' STOE or some in both.

To illustrate these contradictions, in a 32-week professional development program, Tracy Posnanski (2002) found that PSTE was significantly enhanced but their STOE was not. However, Ian Ginns et al. (1995) found significant changes only in STOE. In her study, Posnanski suggested that components of the professional development model positively impacting PSTE were the presence of long-term training, support from colleagues, experimenting with new strategies through practice, and innovative science instructions. The nonsignificant change in STOE was attributed to its stability and/or its measurement problems. In another study, specific to the field of chemistry education, Claudia Khourey-Bowers and Doris Simonis (2004) explored the influence of specific professional development design elements (e.g., instruction in fundamental chemistry concept, modeling the learning cycle, and guided discussion of learning theories). Their results indicated that professional development enhanced both participants' PSTE and STOE. Similar findings were obtained in a 3-year longitudinal study in which both PSTE and STOE increased as a result of participating summer workshops (Chun and Oliver 2000).

There is some evidence suggesting that finding significant increases in efficacy requires that participants enter with lower levels of teacher self-efficacy beliefs. For example, results of a study with 330 science teachers participating in an in-service program that varied from 2 to 6 weeks indicated that in-service interventions had the greatest impact on the efficacy of teachers who began the program with the lowest level of efficacy beliefs. The researchers suggested there was not much room for the growth in self-efficacy for the teachers with high levels of PSTE (Roberts et al. 2001). Consistent with this result, Riggs (1995) reported that teachers who began training with low scores on both PSTE and STOE made gains in PSTE while STOE scores remained constant.

Studies with Preservice Teachers

A large body of research has examined preservice teachers' science teaching efficacy beliefs because once efficacy beliefs are established they appear to be somewhat resistant to change (Woolfolk Hoy et al. 2009). Teaching experiences, courses, and other interventions have produced mixed results regarding teacher efficacy beliefs. Many of these studies have used the STEBI-B as the primary instrument for data. For example, Judith Mulholland et al. (2004) found that the number of science classes completed at the high school level was positively related to preservice teachers' PSTE but not to their STOE. Robert Bleicher (2004) presented similar findings. In addition, he found that age, ethnicity, and teaching experience showed no relationship to either PSTE or STOE. Tarik Tosun (2000) emphasized the importance of preservice teachers' quality of past experiences in shaping their science teaching self-efficacy. Using both quantitative and qualitative data, Watters and Ginns (1995) found that beside their previous experience, a supportive learning environment in teachers' training programs enhanced their teaching efficacy.

Authors suggested that positive self-efficacy stemmed from experiencing exciting, hands-on practical activities. In addition, they attributed the improvement in participants' STOE to experiences with teaching science to young children.

Science Content Knowledge

A few authors have studied science content knowledge as a factor that has been linked with increased self-efficacy of elementary teachers. For example, Kenneth Schoon and William Boone (1998) found that preservice teachers who held fewer numbers of alternative concepts in science had significantly higher efficacy levels. These alternative conceptions act as fundamental barriers to fully understanding scientific phenomena presented in science courses and thus preservice teachers feel less able to teach science to others. However, Patricia Morrell and James Carroll (2003) claimed that science content knowledge alone is not sufficient to improve self-efficacy. In their study, they found that students enrolled in the science methods course showed significant gains in PSTE.

Methods Courses

David Palmer (2006a) also examined the retention of efficacy beliefs after a science method course. He reported that positive changes were recorded for both PSTE and STOE over the period of the course itself and after the delay period. A mixed-method design study by Bleicher and Lindgren (2005) explored the relationship between changes in levels of science teaching self-efficacy and participation in a constructivist oriented science methods course for preservice elementary teachers. Results showed that preservice teachers demonstrated significant increase in conceptual understanding, PSTE and STOE. Consistent with Watters and Ginns (1995), hands-on activities, minds-on activities, and discussion were effective in increasing teaching self-efficacy. Similarly, Posnanski (2007) found that preservice teachers' efficacy beliefs improved more in a constructivist-based science content course than in a traditional one. This constructivist-based course included a nature-of-science aspect and means to mediate self-efficacy beliefs such as vicarious experiences and a positive emotional tone. Regarding the sources of self-efficacy in a science methods course, Palmer (2006b) found that the main efficacy source for preservice teachers was cognitive pedagogical mastery in accordance with Bandura's (1997) assertion that enactive mastery is the most important source of efficacy information.

Discussion and Implications for Further Research

Since its inception in 1977, teacher efficacy has been extensively described and interpreted in the literature as a strong indicator of the teacher's ability to be productive and successful. Not only in science teaching, but also in teacher efficacy research in general, quantitative studies are dominant. Although many quantitative studies assessing science teaching self-efficacy have been conducted, methodological limitations persist regarding the characteristics of the scales that are used. A common concern raised by the researchers regarding teacher self-efficacy scales is the unrealistic optimism of teachers who rate themselves above the average, that is, most preservice and in-service teachers avoid the lower end of the scales and tend to select only the higher values. This presents a problem in intervention studies. Significant changes were observed only for teachers with low self-efficacy at the entry level. Hence, statistical analysis suffers from low variability and ceiling effects.

The STEBI is the most commonly used instrument assessing science teaching efficacy. Henson et al. (2001) stated that the problem of more measurement error in the outcome expectancy (or GTE) sub-dimension also occurred in the STEBI, as it was developed from the TES. In addition, concerns about the construct validity of TES (Tschannen-Moran et al. 1998) also apply to the STEBI as well. A promising instrument, the TSES, was developed based on a model of teacher efficacy. However, the study of science teaching efficacy still suffers from psychometric issues. Considering the well-grounded arguments, we echo the need for a new or revised measure(s) that would reliably assess science teaching efficacy and its components. Ignoring these arguments and going with the already existing measures would suppress the advancement of science teaching efficacy research. More investigations employing qualitative or mixed method designs would help better understanding of this elusive construct (Labone 2004).

Because efficacy beliefs are shaped early, it would be useful to better understand factors that support the development of a strong sense of efficacy among preservice and novice teachers. Future research is warranted to determine possible ways to develop stronger efficacy beliefs by focusing on the sources of self-efficacy beliefs: enactive mastery, vicarious experiences, social persuasion, and arousal. We recommend conducting follow-up longitudinal studies of the science teaching efficacy beliefs of preservice teachers as they progress through the teacher education program and of science teachers at different career stages – early, mid, and late career. It would be desirable to monitor how these beliefs are formulated and sustained throughout the teaching career. Such knowledge would enable teacher educators to modify courses and field experiences to enhance preservice teachers' efficacy beliefs. Several studies have demonstrated that well-designed science methods courses are quite effective in improving science teaching self-efficacy. Courses that are structured to be inquiry based, constructivist in nature, and include use of hands-on activities and group investigations could be beneficial in bringing about appropriate change. In addition, these courses should provide such experiences for preservice teachers as microteaching, cooperative learning, good role models, and a supportive learning environment. Of course, the final question to explore is if these changes in methods courses lead to improvements in teaching efficacy and finally to increases in the science literacy of students in the teachers' classrooms.

Extending the notion of teachers' sense of efficacy, Hoy, Woolfolk Hoy, and their colleagues have discussed the importance of "academic optimism" at the school

(Hoy et al. 2006) and individual teacher levels (Woolfolk Hoy et al. 2008). At both the collective school and individual teacher levels, teacher's sense of efficacy, teacher trust in parents and students, and academic emphasis combine to form a single, strong second-order factor – teacher's academic optimism. Teacher efficacy is a cognitive aspect of academic optimism, the thinking and believing side; teacher trust in students and parents is the affective and emotional side of the general construct; and teacher academic emphasis is the behavioral side, that is, the enactment of the cognitive and affective into actions. Academic optimism has been related to teacher beliefs about instruction and management and to student achievement. Much remains to be done in examining academic optimism and its associations with other variables, particularly in science education field.

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Chapter 32
Context for Developing Leadership in Science and Mathematics Education in the USA

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Leadership is an important component of any field of endeavor; the field of science and mathematics education is no exception. Little is known, however, about leadership in this field, about who become leaders, what skills are required, and how leadership develops. To answer some of these questions, the National Science Foundation supported a project at Michigan State University to advance understanding of the context of leadership in science and mathematics education. The project addressed the following research questions:

- What are the characteristics of current leaders who influence science and mathematics education in crucial arenas of educational activity?
- What educational and professional experiences led them to their positions of leadership and influence?
- What has been the role of leaders in influencing the direction and quality of science and mathematics education?
- Where will the next generation of leaders come from, and what kind of preparation will they need?

The study consisted of three parts including a review and analysis of existing literature and databases, interviews with a sample of current leaders in the field, and an examination of a sample of doctoral programs that serve as training grounds for new

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leaders in the field. The study was conducted during 2001–2003, with data analysis continuing to the present time; 68 recognized leaders in science and mathematics education, with at least 15 years of experience in the field, were interviewed. Also, 20 doctoral programs (ten each in science education and mathematics education) were studied through document review, questionnaires, and interviews with program deans, faculty members, and recent graduates at the doctoral level. A conceptual model was developed to guide the study, and later modified based on the findings.

Research Design

Literature Review and Analysis of Databases

Literature related to leadership in science and mathematics education was examined along with literature on leadership in other professional fields. Relevant databases were identified and examined for information that could aid in understanding leadership and its development.

Interviews with Current Leaders

A plan for interviewing approximately 80 recognized leaders in science and mathematics education was devised, with ten leaders to be interviewed in each of eight subfields including curriculum, assessment, undergraduate and pre-college teaching, doctoral programs, teacher education, professional development, research, and educational policy. Leaders to be included in this part of the study were identified by project staff, starting with lists of people on editorial boards, involved with major projects (e.g., development of national standards), serving as organizational leaders, and so on. Further nominations were solicited from some of those so identified as leaders and from our national advisory board. Those to be interviewed were selected from this larger pool with advice from the project's national advisory panel. The sample selected spanned the variability in the field along several dimensions, including perspectives about the goals of science and mathematics education, position (leaders by virtue of holding office vs. others who have not held "official" positions), function (to include idea generators, implementers, collaborators who can catalyze others, etc.), and status (leaders who have received awards for their work, and leaders who have been less visible but highly effective).

An interview protocol was developed that focused on background information and three episodes from early-career, mid-career, and recent events that highlighted the development of leadership. The interview protocol was tested and refined by project leaders in face-to-face and telephone settings. A project leader contacted each interviewee and a time for an hour-long telephone interview was established as soon as consent was gained. Interviewers, including both project faculty and graduate students, were trained to conduct the interviews by telephone. All interviews were recorded, and selected quotations from interviews were transcribed. Data were then entered into Filemaker Pro, which was used to support individual- and cross-case analyses.

Examination of Selected Doctoral Programs

Data on production of doctorates in science and mathematics education in recent years were collected from several sources, including Dissertation Abstracts and surveys conducted by the National Center for Educational Statistics. For both mathematics education and science education, a sample of programs was selected to include well-known, visible programs that have produced large numbers of mathematics and science education PhDs over several years. Other programs were included to ensure some variability in geographic location, program structure, and distinguishing features such as success in the production of graduates from minority groups.

We selected ten doctoral programs in science education and ten in mathematics education for study. Project leaders contacted a key staff member in each program to explain the study and secure necessary permissions. Telephone interviews were conducted with the dean who oversaw the program, at least one key faculty member in the program, and two recent doctoral graduates, between 2 and 7 years after completion. Tape recordings of the interviews were summarized as a first step in data analysis. Three additional sources of information were requested from the program faculty members: (1) written responses to a questionnaire regarding specific data on the faculty, the student body, courses included in the program, and support that faculty and students received from varied sources; (2) program plans for five recent graduates, and (3) sample syllabi for key courses in the program. These data were analyzed to provide additional evidence about the experiences graduates received in their program.

Findings

Literature Review and Analysis of Databases

Initial reviews of literature on leadership pointed to difficulties in studying leadership because its dimensions and definitions are not clear and the variety of social influences that affect it remain poorly defined (Pfeffer 1977). One factor that further complicates the study of leadership in science and mathematics education is that leaders in the field may or may not hold formal positions of leadership, whereas most other leaders, such as those in business and government, hold a position with a title and other publically recognized attributes that clearly identify them as leaders. In science and mathematics education, recognition as a leader is often achieved as a result of the creativeness and utility of individuals' ideas, which guide their research, developmental work, and publication.

Further complications arose because there had been little, focused, prior study of leadership and its development in this field. Willard Jacobson, who examined 50 years of science education research, helped us to understand one component of leadership within the science education community (Jacobson 1975); 20 years later, Paul Joslin and Karen Murphy added to that work in a report that was recently published (Joslin at al. 2008). George DeBoer's (1991) work on the history of science education also described the evolution of the field and many of its key players. Robert Yager and James Gallagher's (1982) study of the nation's 35 largest doctoral education centers in science education showed a deficiency in the number of younger professors.

A recent book by two prominent leaders in the field, *Inside Science Education Reform* (Atkin and Black 2003), offers important insights about leadership in science education. These two leaders each give a personal history of their professional development over half a century. Their pathways to leadership differ from one another, highlighting features that were helpful in designing interviews and data analysis for the proposed research. In a complementary work, Kenneth Tobin and Wolff-Michael Roth (2006) compiled an anthology of brief autobiographies of leaders in the field of science education. This autobiographical genre holds promise in delineating varied pathways to leadership and characteristics of leaders in the field.

Research on leadership is also sparse in mathematics education. A study undertaken by Carmen Batanero et al. (1994) concluded that increased availability of formalized graduate programs in mathematics education in universities indicated the consolidation of the academic discipline of mathematics education and its recognition as a field of research. Robert Reys et al. (2001) produced a status report on doctoral programs in mathematics education, providing information about trends in doctoral preparation over the past 20 years. Part of their study addressed the faculty members working in mathematics education in doctorate-granting institutions. They found that 79% of current faculty in such institutions would be eligible for retirement within the next 10 years, signaling an impending major shortfall of available faculty.

Other studies of mathematics and science education leadership, such as those done by Reys (2006), Peter Hewson (2001), and Michael Battista (1994), helped us to refine our conceptualization of "leadership."

In addition to literature reviews, we used data from national surveys. Dissertation Abstracts and the NCES Integrated Postsecondary Education Data System gave us information about numbers of doctoral degrees being granted; the NCES School and Staffing Survey gave us limited information about assumption of leadership roles by teachers and other educational personnel. The National Research Council's

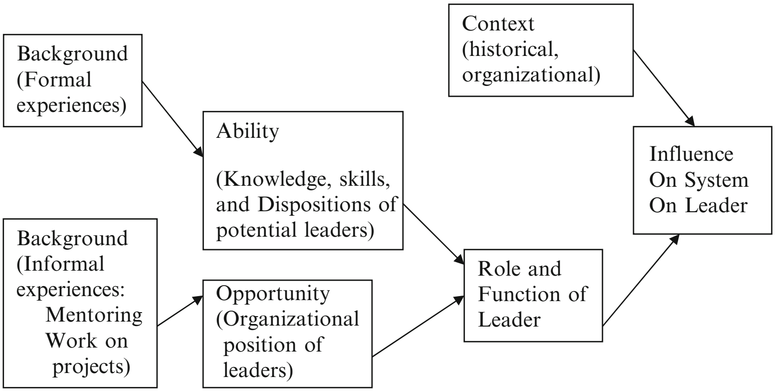

Fig. 32.1 Leadership development model

studies of graduate education (e.g., NRC 1999) were useful sources both for data and methodology.

As anticipated, we found difficulties in interpreting the data that were routinely collected because of imprecision in definitions used for the data. For example, data from Dissertation Abstracts provide an inflated picture of the number of potential leadership personnel for science and mathematics education, as well as the number of potential faculty members who are capable of, and interested in, the routine work in the field. The problem arises because dissertation writers can classify their theses as they wish. As a result, many people in reading and educational psychology who study science or mathematics learning or teaching for their dissertation research may be classified as science or mathematics educators, even though they may not have expertise that qualifies them as professionals in those fields. This inaccuracy of classification does not diminish the importance of their research to the field, but it does give a false picture of the number of people willing and able to engage in science or mathematics education as a career, in teaching methods courses, in providing subject-specific staff development, in developing curriculum and assessment resources, and in contributing to educational policy specific to mathematics or science education.

Conceptual Model for the Project

To clarify the process of leadership development in mathematics and science education, we used the above conceptual model (Fig. 32.1) to guide our investigations and interpretation of data from them. Based on prior research on leadership development, we included factors such as leaders' personal and professional background, motivation, and knowledge related to the eclectic field of science or mathematics education. We also felt that the special abilities and energy that leaders possessed were important factors in leadership in a professional field, and we hoped to learn about the genesis of opportunity, responsibility, and influence through this study.

Interviews with Current Leaders

Several findings emerged from the interviews and are highlighted in the following pages relevant to each research question.

What are the characteristics of current leaders who influence science and mathematics education in crucial arenas of educational activity?

- Interviews were completed with 68 leaders in science and mathematics education with 15 or more years of experience. For leaders with 25 or more years of experience, 69% of the sample was male; for leaders with between 15 and 24 years of experience, the gender balance shifted to a slight majority of females.
- In this sample, 40% of the leaders had earned doctoral degrees in science or mathematics education; 25% held doctoral degrees in science; 3% in mathematics; 24% in measurement or psychology; and 8% in education. Nearly half of the leaders interviewed earned a Bachelor's degree in science and 38% held a Master's degree in science.
- Leaders in the field exhibited important personal qualities including high levels of commitment, tenacity, energy, enthusiasm, confidence, and humility. The majority of the leaders interviewed were altruistic, visionary, entrepreneurial, open to new ideas, and scholarly in their approach.
- Nearly all had high energy and tended to work long hours. Workweeks of 60 or more hours were commonplace. Of equal importance, leaders knew their field well and were able to bring relevant ideas together in framing research questions or solutions to specific problems.
- Most leaders were charismatic, able to excite others with their enthusiasm. Interpersonal skills were complemented by skills in writing and public speaking.
- Several leaders spoke about their "passion" to improve teaching and students' learning in an area of science or mathematics.

What educational and professional experiences led leaders to their positions of leadership and influence?

The data showed that pathways to leadership were highly varied. While leaders of a particular age-range often traced the early development of their careers to experiences in National Science Foundation summer institutes for teachers, an important feature in many of the leaders' developmental scenarios was "taking advantage of opportunities" to play a significant role in a project. At the time the opportunity arose, the leader often felt unsure about his or her capacity to succeed in the new role, but having accepted the opportunity, was able to perform well. Further, success at one leadership task led to more opportunities, and more confidence, to exercise leadership.

The following points highlight additional key findings from the interview data:

- In spite of their energy, background, and confidence, several leaders faced a steep learning curve with their early career positions. Crucial skills and knowledge for "retooling oneself" for new developments in the workplace were needed, such as interacting in new discourse communities, working effectively with professional colleagues, and dealing with new research methods, subject matter content, and proposal writing.
- Particular leadership opportunities were strong influences in career paths. Nearly two-thirds of the leaders identified a specific role that had been significant in their career development, influencing their thinking, visibility, reputation, networks, and future opportunities.
- Nearly all of the leaders interviewed had an apprenticeship period with a mentor, who supported their development as leaders.
- A "norm of collegiality" enabled most leaders to benefit from mentors and many said that mutual learning was common for both mentor and mentee.
- Factors influencing the professional work of leaders were quite varied, ranging from their own dissertation research, prior experiences and understandings, research-based principles and theories, particular research skills, their own philosophy and interests, and practices learned from other societies or cultures.

The range of responses about ideas and experiences informing the leaders' work was surprisingly broad, yet highly informative. This range underscores the individual and creative character of research and development in science and mathematics education.

What has been the role of leaders in influencing the direction and quality of science and mathematics education?

Interviews provided evidence that leaders had exerted a large influence on the character and directions of the field during their careers, which range from 15 to more than 40 years. Moreover, it appeared that their claims were not overstated, as a tendency toward humility, seemingly engendered by the awesome responsibility of educating teachers and developing curriculum and policies that affect large numbers of children for many years, overshadowed any excesses in statements.

Leaders had influenced the field in many ways through their individual and collaborative efforts, including:

- New research questions, methods, paradigms, and centers of excellence for research and development in the field that have strengthened and advanced the nature and quality of research in the field.
- New, broader, more socially appropriate goals and standards for the field, as well as new curricular and assessment resources to support improvements in teaching and student learning.
- High-quality programs in teacher education and staff development for prospective and practicing teachers that are grounded in research, and reflect new educational goals and standards.
- Educational policies that are contributing to improvements in research, curriculum, teaching, teacher education, and students' learning.

- A better understanding of learning, teaching, and the connections among goals, assessments, teaching models, and learning activities, which resulted from research and scholarship.
- Larger, more active professional organizations, and improved professional journals that support a scholarly atmosphere in the field.

Overall the leaders in this study described their work, and its outcomes, in positive terms. They had seen the field of science and mathematics education change substantially over their professional careers. Each also felt that his or her work had an influence on some part of a massive, complex educational enterprise.

Where will the next generation of leaders come from, and what kind of preparation will they need?

In the design of the study, we sought to shed light on this concern, with special emphasis on what preparation will be required by potential leaders in the field. Thus, we chose to explore perceptions of the challenges and issues that confronted the field, at the time of the study and in the near future.

Interviewees, including deans and faculty members involved in doctoral programs, identified several challenges to the field. The most frequently cited challenge facing the field was the need for new leadership. This was in recognition of the aging of current leaders and the shortage of new people at mid-career levels over the past decades, for reasons identified earlier in this chapter.

A second challenge identified by interviewees was the gulf that exists between science and mathematics educators and two key sets of colleagues – teachers in schools and faculty in science and mathematics departments. Part of the difficulty is that the eclectic nature of science and mathematics education is not well articulated as a strength. Instead, academic colleagues frequently perceive it as a weakness. A major difficulty is that the field lacks an integrated conceptual framework to guide its work. As a result, the field frequently is influenced by fads, which critics perceive as ineffectual both from a scholarly and practical standpoint.

Other challenges and issues that were perceived as confronting the field, according to the leaders, included:

- Assessment-based accountability programs, such as No Child Left Behind, which appear to be driving instruction away from understanding and higher-order thinking, toward low-level learning emphasizing factual recall.
- Teacher education seen as failing novice teachers, while requiring large investments in professional development for reeducating practicing teachers.
- The gap between researchers and practitioners regarding the value of theory and research.
- Inconsistent policies and fluctuating support for research and development from the federal government and other agencies.

An implicit assumption underlying deans' and faculty members' views of present-day challenges is that doctoral education needs modification. Existing programs have not attracted sufficient numbers of students, student diversity is too limited and new knowledge and skills are needed to address the challenges facing the field. Therefore, existing doctoral programs should (1) give more emphasis on meeting these challenges, (2) modify program requirements so that graduates have the knowledge and skills to better address the learning needs of science and mathematics teachers and their students, and (3) increase attention to recruitment of students, including minorities.

One added finding from the interviews of deans and doctoral program faculty members was the lack of emphasis on leadership development in their thinking and program structures when the topic was raised in our interviews. Many said that they had not given leadership development much thought prior to its mention in the interviews. Further, all agreed that it was an important, but overlooked, dimension of doctoral-level education.

Examination of Selected Doctoral Programs

Data reported in this section of the study refer to ten science education doctoral programs in our sample. The programs studied were those at the following universities: Michigan State University, Montana State University, North Carolina State University, Purdue University, Teachers College-Columbia, Texas A & M University, the University of Georgia, the University of Texas at Austin, the University of Wisconsin at Madison, and the joint program at San Diego State University and the University of California at San Diego. Two of the programs were less than 10 years old, whereas the others had been in operation for over 40 years. Programs also differed in their location within the university structure. The varied organizational patterns show that there are multiple "models" for science education doctoral programs in the USA; this is also reflected in the diversity of courses offered and program requirements. Only one program was discipline-centered, focused on chemistry education; the others all dealt with education in all of the sciences.

In these ten programs, there were 84 faculty members at the time of the study in 2003, with 52% full professors, 26% associate professors and 20% at the assistant professor level; only two faculty members in these ten doctoral programs were not part of the tenure stream. All tenure stream faculty members held doctoral degrees.

These 84 faculty members earned their doctoral degrees at 44 different universities, though six universities had produced 26 (31%) of the faculty working in the programs we studied. Doctoral specializations of the program faculty were as follows:

- 51% science education
- 24% science (physics, biology, etc.)
- 17% reading, psychology, adult education, feminist theory
- 4% in history of science
- 4% technology education

In 2001, 232 doctoral students were enrolled in the ten programs, with the following demographic characteristics:

- 80% of these students were US citizens
- 20% international students
- 37% female
- 81% White, non-Hispanic
- 9% African-American
- 7% Asian-American
- 2% Hispanic-American
- <1% Native-American
- Two-thirds were full-time

The mean number of students enrolled at each of these programs was 23.2. Considering that students typically are enrolled for 4–5 years for doctoral study, the average number of students entering per year was about 5, with an average of about 3 people per program completing their degree programs each year. Compared to the number of open vacancies in this field, these ten programs do not seem to be producing an adequate number of students to meet the needs of the job market. The shortage of faculty for US programs is made more pronounced because about 20% of enrolled students are foreign, with most returning to their home countries on program completion. Another notable feature about enrollment at the ten science education programs is the low representation of minority students, which will continue the limited cultural diversity within the field.

Doctoral Program Requirements

Doctoral programs studied vary considerably in requirements for admission and graduation, and level of student financial support. However, all programs require an extensive dissertation, with graduate level courses to prepare students for this research and to become working members in the discourse community that carries out research, development, and teacher education in science. While assistantships provided financial support for students at all institutions, only one program claimed that all students received support every year. In several programs, availability of assistantships depended on variations in the university's available budget and external funding.

The ten programs exhibited wide variation in number and kinds of courses or credits required for completion of doctoral study, ranging from 14 to 36 courses or the equivalent of 36–90 credit hours for both coursework and dissertation in science education. Different degrees of flexibility in program requirements also were found among the ten programs. That is, some programs have specific course requirements while others allow students and advisors more choice in program planning, depending on interests and career aspirations. Five of the programs do not have specified course requirements in science, but there is an expectation that, on completion of the doctoral program, students will have a strong background in science that approximates a

Master's degree. In these programs, candidates may enter with a Master's degree in science or they may enrich their background during the program.

Other emphasis areas identified by faculty include multicultural science education, technology, teaching strategies, cognitive science, and research. Three of the ten science education programs strongly promote multicultural science education. Most programs have some requirement for application of technology in teaching.

Research courses in both qualitative and quantitative methods are a part of all programs, although emphasis varies from three to ten courses, with a median of four.

While the researchers in this study knew that doctoral programs in science education differed, the degree of difference among these ten was quite surprising. Perhaps the field needs to address standards for doctoral level education.

Interviews with Recent Graduates

As part of our study we interviewed 20 recent graduates from the ten science education doctoral programs, asking for their perceptions of the program and of their preparation for their present career.

The recent graduates interviewed in this study were generally positive about their doctoral preparation. The vast majority valued program components such as assistantships, mentoring from advisors, dissertation, and other research experiences, as well as opportunities to make presentations at professional meetings. These opportunities were mentioned far more frequently than formal courses as important preparation for their current and future jobs. Recent graduates indicated that the collegial atmosphere in their doctoral programs was an important, positive aspect in their professional development. Unfortunately, not all had the opportunity to serve on projects or university committees, which limited their enculturation into the science education community.

Most of the recent graduates felt that they were treated as partners in this work, and this engendered confidence for their first postdoctoral positions. In contrast, while most recent graduates were pleased with their assistantships, nearly a quarter of them expressed concerns that this entailed "doing the professor's work for them." Perhaps, faculty members could be more explicit about the role of assistantships as part of professional development in the overall doctoral program, making the essential place of specific work more clear.

Most recent graduates said they had the opportunity to copresent research papers with their professors or present their own papers at professional meetings, to meet other members of the science education community, and join professional associations. As they entered their first postdoctoral positions, the graduates felt they were well prepared to write papers and present at conferences; they have continued to write and present.

When asked, all the recent graduates indicated that the idea of having coursework prior to dissertation research was useful in introducing them to new ideas that supported development of conceptual frameworks for their dissertation research, teaching, and other professional work. Although most had teaching experience, many lacked practical understanding of how schools work and how reforms come about. The recent graduates also appreciated learning theoretical constructs on learning, teaching, schooling, qualitative and quantitative research methods, critical thinking, and skills related to educational applications of technology, that influenced their dissertation research, and which they carried with them into their careers. Also, experience in writing grant proposals, and teaching science methods and other science education courses, ranked high regarding preparation for their careers.

In contrast, four out of the 20 recent graduates interviewed did not feel that they were well prepared for their current positions as professors in science education, because they had little or no coursework on pedagogy during their doctoral studies. These sentiments came from graduates from programs that are either content focused or located in departments that are isolated from the Colleges of Education. These recent graduates felt that they could have benefited more from interacting with and taking courses from science education professors. These four also felt that they did not have adequate mentoring as potential leaders during their doctoral programs. Because this represented 20% of the sample, it is cause for concern.

When recent graduates were asked about doctoral programs as preparation for leadership, responses were mixed. About half were confident that their programs prepared them to be leaders in the field, whereas the other half thought they had not been helped to develop as leaders. The majority of individuals who thought they were prepared to be leaders felt that the programs themselves were not meant to prepare leaders. These people said they made an individual choice in favor of assuming a leadership stance. The majority of recent graduates who perceived that they had emerged as leaders attributed the development of this quality to their programs, and specifically to professors who were not "out for their own glory," but supported and believed in their students.

On the other hand, the recent graduates who did not perceive their programs prepared them to be leaders fell into two categories: The first are those who now see themselves as potential leaders in the field; the second say they never aspire to be leaders of any kind. Some of those who see themselves as potential leaders thought that their programs taught them to be more thoughtful, but faculty did not encourage them to write, publish, or present at conferences. Two students described tension that existed between faculty members who differed in their encouragement of students to publish and present papers.

Conclusion

Based on the findings of this study, a revised, more elaborated conceptual model of leadership development in science and mathematics education was constructed that includes emphasis on the personal qualities of leaders and how leadership develops throughout a career in response to forces within the professional community and the larger society. This model is shown as Fig. 32.2.

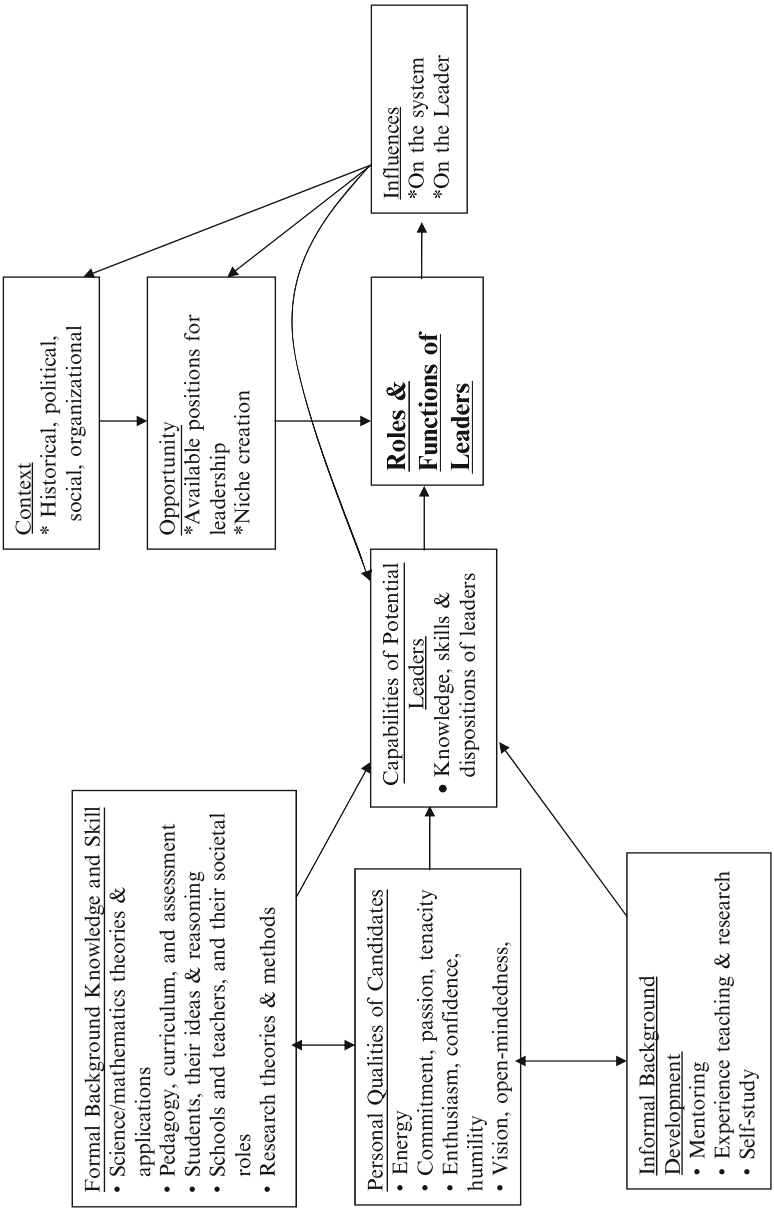

Fig. 32.2 A revised model of leadership development

It is our strong recommendation that deans, doctoral program faculty, and those who influence educational policies give attention to strengthening doctoral programs in science and mathematics education to improve both the number and quality of graduates, including adding leadership development as a program goal. In addition, because continuing high-level support for doctoral programs, and for research in the field, is essential to maintain quality programs and a steady supply of personnel to carry on the work of the field, we also strongly recommend that universities, foundations, and governmental agencies provide more stable funding for doctoral programs in science and mathematics education, and for research in these fields.

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Chapter 33
Research on Science Teacher Beliefs

Lynn A. Bryan

In the mid-1980s, the confluence of the publication of the three landmark documents [*A Nation Prepared: Teachers for the 21st Century* (Carnegie Commission Task Force 1986), *Handbook of Research on Teaching*, (3rd ed., Wittrock 1986), and *Tomorrow's Teachers* (The Holmes Group 1986)], advances in cognitive psychology (particularly as it pertained to teaching), and the increasing popularity of qualitative approaches to educational research propelled research in the domain of teacher thinking in a new direction. Researchers saw promise in examining and understanding the mental constructs and thought processes underlying teacher behavior as a way to yield meaningful changes to practice. A marked shift occurred in how teacher education research was framed – from a *training* perspective that identified and examined the most effective instructional approaches for preparing teachers to perform specific behaviors to a *learning* perspective that sought to understand teachers' knowledge development. Teacher educators began to examine teachers' knowledge and educational beliefs, how knowledge and beliefs change over time, and how teachers' translate knowledge and beliefs in to classroom practices. Research began to focus on the integral relationship between beliefs and actions in order to develop a complete and useful understanding of teachers' thought processes (Cochran-Smith and Fries 2005). Concomitantly, new reform initiatives were emerging in science education, particularly in the USA, calling for the implementation of widespread, diverse, and substantial innovations in science classrooms. Hence, the need to examine teachers' beliefs in relation to their decision making about classroom practices became paramount.

More than two decades later, the field of science education has amassed a literature base on teacher beliefs that establishes that teachers are creative, intelligent decision makers who hold complex systems of beliefs that influence how they view students,

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themselves, and science. Science education research has moved from simply describing beliefs and practices toward developing explanations for how beliefs influence practices and vice versa (i.e., why teachers do what they do in the science classroom). This review of international studies on science teacher beliefs attempts to depict the most salient themes that have emerged from more than 25 years of science education research on teacher beliefs. It is not an attempt to report an exhaustive review of literature, but instead provide a survey of informative studies in the field from an international perspective. In addition, this review primarily focuses on research that examines teachers' epistemological and pedagogical beliefs, and does not include large subsets of research literature related to science teacher beliefs such as teacher knowledge, attitudes, and self-efficacy beliefs.

Defining Beliefs

As research on teacher beliefs has gained attention in the science education literature over the past two decades, it is well noted that there is not one consensus definition of beliefs consistently used in the literature. Pajares (1992) referred to the problem of defining beliefs as "at best a game of player's choice" (p. 309), noting that one may find numerous aliases for the construct of beliefs in educational literature. Nonetheless, several works have emerged as being influential in the conceptualization of beliefs as a guiding construct for contemporary teacher thinking research. Among the most prominent scholarship cited in science education research are the works of Milton Rokeach (1968) and Thomas Green (1971), Jan Nespor's Teacher Belief Study (1987), and Frank Pajares's review of teacher belief research (1992). Reviews and analyses of this literature contribute to a consensus that beliefs are part of a group of psychological constructs that describe the structure and content of human thought that is presumed to drive a person's actions. In addition, keeping with the traditional philosophical literature, the term belief implies a construct different from knowledge. Green (1971) stated that while knowledge and beliefs are remarkably similar, the difference between them "seems to lie in the truth condition" (p. 69). Similarly, according to Pajares (1992) the most commonly, albeit "artificially," used distinction between beliefs and knowledge is: "Belief is based on evaluation and judgment; knowledge is based on objective fact" (p. 313). In other words, knowledge carries a kind of epistemological assurance that beliefs do not. Furthermore, from this research a number of fundamental assumptions that characterize beliefs can be derived:

- Beliefs do not exist in complete independence of one another, but are structured into an "internal architecture" of systems that are psychologically, but not necessarily logically organized.
- Not all beliefs are of equal importance to the individual. They are prioritized according to their relationship to other beliefs or other cognitive and affective structures.

- Beliefs are held along a continuum of centrality – some are more central, core, or primary, than others. It follows that the more central a belief is, the more resistant to change that belief will be.
- When a belief is changed, the centrality of that belief has repercussions for the entire belief system.
- Beliefs are far more influential than knowledge in discerning how individuals frame and organize tasks and problems and are stronger predictors of behavior.

Finally, there is a complex relationship between beliefs and actions. Rokeach (1968) argued that what a person espouses as a belief may or may not represent accurately what the person truly believes. He suggested that beliefs cannot be directly observed, but rather beliefs "must be inferred as best one can, with whatever psychological devices available, from all the things the believer says or does" (p. 2). In this vein, what a teacher does in the classroom is representative of his or her beliefs and should not be taken as a separate entity from a teacher's belief system.

Regardless of the limitations or concerns about the definition of beliefs, we do know that beliefs are personal constructs that may provide an understanding of a teacher's practice, and the nature of that relationship, while not simple, is becoming better understood and described in science education research.

Methods for Ascertaining Beliefs in Science Education Research

Science educators have employed numerous methods for ascertaining and reporting on teacher beliefs. When investigating teacher beliefs, most researchers make a distinction between espoused beliefs and beliefs as they are inferred from practices.

Espoused Beliefs

Espoused beliefs are self-reported claims about the way things are or should be. In other words, espoused beliefs are what we say, but not necessarily what we do. Interviews, questionnaires and Likert-style surveys are commonly employed to determine teachers' espoused beliefs. Many researchers design their own context-based instruments such as semi-structured or structured interview protocols and theoretically grounded surveys based on characteristics of a specific national curriculum or intervention programs. Within the last decade, several standardized protocols and validated surveys have been disseminated through the science education literature, including *Attitudes and Beliefs About the Nature of and the Teaching of Mathematics and Science* (McGinnis et al. 2002), *Context Beliefs About Teaching Science* (Lumpe et al. 2000), *Inventory of Scientific and Pedagogical Beliefs* (Porlán 1989 as cited in Porlán and Martín del Pozo 2004), and *Teachers' Pedagogical Philosophy Interview* (Richardson and Simmons 1994 as cited in Simmons et al. 1999).

While quantitative survey instruments and questionnaires such as those described above assist in the comparison of teachers' espoused beliefs (particularly over large populations and between studies), they often veil the details of teaching–learning interactions and the contextual nature of teachers' beliefs. To uncover the idiosyncrasies and contextual nature of teacher beliefs, several studies have employed methods that require teachers to respond to various prompts such as classroom scenarios. One such methodology is the repertory grid technique based on Gregory Kelly's (1963) personal construct theory. Examples of studies that used this technique include the works of John Olson (1981) and Hugh Munby (1984).

Additionally, science educators have used critical incidents, metaphors, and case-based approaches to educe a more detailed portrait of teachers' beliefs. For example, Nam Hwa Kang and Carolyn Wallace (2004) used critical incidents as a tool for identifying teachers' epistemological beliefs. Ken Tobin and colleagues have used metaphors as a vehicle to elicit teachers' beliefs about teaching and learning (e.g., Tobin and LaMaster 1995). Sandra Abell et al. (1998) ascertained teachers' pedagogical beliefs using video cases and a series of reflective prompts in which teachers responded to video case scenarios of other teachers' instruction.

Beliefs Inferred from Teachers' Actions

Espoused beliefs may or may not be consistent with the actions carried out by an individual. Hence, many studies in science education examine teachers' beliefs-in-action: the beliefs that implicitly guide and are inferred from teachers' actions. Methods used to examine teachers' beliefs as inferred by their actions include prolonged field observations documented in field notes, observational protocols, and videotaping. For example, over the past several years, science educators have begun to use digital editing tools to help teachers build "cases" of their own teaching not only for research purposes but also for facilitating teachers' reflection upon and refinement of their beliefs and practices. The *Video Analysis Tool* is a web-based resource that has been used in several teacher belief studies while also serving as a robust and flexible pedagogical resource for teacher education courses (Bryan and Recesso 2006). Randy Yerrick and colleagues (2005) have used *iMovie* for similar purposes. Within the last decade a few standardized rubrics for gathering observational data for teacher belief research have been disseminated through the science education literature including the *Secondary Teacher Analysis Matrix* (Gallagher and Parker 1995 as cited in Simmons et al. 1999) and *Science in Schools Component Mapping* (Tytler et al. 2004).

Salient Themes in Science Education Research on Teacher Beliefs

Many significant contributions to understanding teacher beliefs have been made by scholars in the field of science education. This research presents a portrait of both prospective and practicing teachers who hold deeply entrenched beliefs about teaching and learning, their students, and subject matter. Many studies profile teachers' beliefs in a "snapshot" of time, portraying espoused beliefs as congruous or incongruous with teachers' actions in the classroom. This research is unquestionably important, but should not be construed as implying that beliefs cannot change. Indeed, beliefs are strongly held and relatively static in nature (Rokeach 1968); however, they can be provoked to change. Studies that examine change in beliefs over time often occur within the context of a teacher education program or an intervention aimed at facilitating teachers' refinement of beliefs and actions to be congruous with reform initiatives. Finally, there is a small but emerging set of studies that examine the complexity of teacher beliefs and belief systems.

Congruity Thesis

A number of studies have concluded that s*cience teachers possess beliefs about teaching and learning that influence their classroom practices.* This subset of beliefs literature demonstrates a congruity thesis – that is, the findings depict congruity between a teacher's espoused beliefs and classroom practices. The congruity thesis especially seems to hold true for teachers who espouse empiricist/positivist views about science and behaviorist/transmissionist beliefs about learning.

In her seminal case study, Nancy Brickhouse (1990) examined the nature of science beliefs and teaching practices of one US beginning middle school teacher and two US veteran high school science teachers. The two veteran teachers' understandings of the nature of science and how students learn science formed a consistent set of beliefs for guiding their classroom practice. However, many obstacles prevented the beginning teacher from implementing instructional strategies that were congruous with his beliefs. Brickhouse concluded that teachers' beliefs about the nature of scientific theories, the nature of scientific processes, and the progression and change of scientific knowledge influenced not only their explicit lessons but also an implicit curriculum about the nature of science.

Teacher beliefs about themselves and students as knowers of science have also been shown to influence teachers' classroom practices. Bernard Laplante (1997) reported on the profound influence that the epistemological beliefs of two Canadian elementary teachers had on their choice of teaching strategies. The teachers viewed themselves as consumers of science knowledge (as opposed to inquirers of science) and science as a body of knowledge (as opposed to a process of inquiry). Their teaching reflected these beliefs – the use of teacher-centered strategies in which students engaged in closely controlled activities and were cast as receivers of decontextualized knowledge transmitted by the teacher.

A system of reinforcing beliefs that included traditional positivist-empiricist beliefs and a belief about control of the classroom were found to be particularly influential in driving the practices of a 14-year veteran Mexican high school biology teacher, Maria. In their in-depth case study, Janet Verjovsky and Guillermina Waldegg (2005) concluded that Maria possessed a strongly held system of beliefs that was markedly coherent with her practices. This belief system served as a powerful filter through which Maria unconsciously interpreted new models of teaching and learning and resulted in difficulties in establishing a collaborative learning environment.

The congruity thesis has been demonstrated among prospective teachers as well. In a study of 74 secondary student teachers at the University of British Columbia, Jose Aguirre and colleagues (1990) examined student teachers' beliefs about the nature of science, science teaching, and science learning. Nearly 50% of the student teachers held a belief about teaching as knowledge transfer from sources of authority (such as the teacher's mind and textbooks) to the students "empty" minds. Correspondingly, nearly 50% of student teachers viewed learning as the intake of knowledge. They concluded that holding a positivist-empiricist view of science may be a significant disposition leading student teachers to adopt a more transmissive approach to teaching.

While the majority of studies that demonstrate congruity between beliefs and practices focus on empiricist/positivist views about science and behaviorist/transmissionist beliefs about learning, notably there are a few studies that portray teachers whose classroom practices are congruous with their espoused constructivist epistemological beliefs. For example, in a study that examined teachers' beliefs about the nature of science, Larry Bencze et al. (2006) found that Canadian teachers' espoused beliefs about science, whether positivist or constructivist, broadly corresponded to their tendencies to control student knowledge building or promote student-centered, open-ended scientific inquiries. Specifically, the pedagogical repertoire of teachers who believed that science involves highly systematic methods that lead to conclusions matching reality tended to include teaching practices such as lectures, multimedia presentations, whole-class guided questioning, text reading, and completion of worksheets. On the other hand, when teachers held beliefs that were congruous with a social constructivist view about science, they utilized practices that enabled students to engage in student-directed, open-ended scientific inquiry projects in which students designed their own methods to develop and evaluate knowledge claims.

Similarly, Maher Hashweh (1996) found in a study of Palestinian teachers who held contrasting epistemological beliefs that constructivist teachers used multiple strategies to facilitate students' learning of new conceptions including the elicitation of alternative conceptions and facilitating cognitive restructuring. They had a richer repertoire of teaching strategies. On the other hand, empiricist teachers used presentation of information, explain-and-convince methods, and repetition strategies more often. Hashweh concluded that the effects of teachers' epistemological beliefs are strong and stable across teachers' field of expertise in science and the education level at which they teach.

Influence of Teacher Beliefs on Science Curriculum Implementation

The studies described so far have examined the congruity of teachers' beliefs vis-à-vis their classroom practices so as to establish the influence that beliefs have on teachers' practice. Another set of studies that have demonstrated the influence of science teachers' beliefs on their practices are those conducted in the context of implementation of curriculum innovations and science education reform initiatives. In these studies, the teachers' beliefs and practices, while congruous, typically were in direct contrast with important reform-oriented elements and goals of the innovations. The predominant findings in these studies portray teachers who translated reform-oriented initiatives to "fit" with teaching practices that were strongly supported by their espoused beliefs. These studies document the critical relationship between teachers' beliefs and instructional decisions and demonstrate that *teachers' beliefs mediate the curriculum implementation process.*

For example, one of the earliest studies examining science teachers' beliefs in the context of reform-based curriculum implementation was conducted by John Olson (1981). In this study, Olson examined the beliefs and practices of eight Canadian teachers who participated in the implementation of the English Schools Council Integrated Science Project (SCISP). Utilizing the repertory grid technique, Olson elicited "a picture of [the teachers'] thinking about classroom activity, and particularly about relationships with the students" (p. 262). Olson found that when the teachers attempted to implement the innovative curriculum, they confronted dilemmas as they became aware that how they wanted to proceed with implementation was at odds with the project goals and "doctrine." In the end, teachers either ignored important elements of SCISP that were not resonant with their beliefs, or transformed the curriculum to align with their traditional beliefs about the teacher's role in the science classroom which entailed controlling the direction and goals of the lessons.

Linda Cronin-Jones' (1991) naturalistic case study of two US middle school science teachers portrayed a similar influence of teacher beliefs on curriculum implementation. She found that teachers' beliefs about how students learn, teachers' role in the science classroom, the ability levels of students, and the relative importance of science topics strongly influenced teachers' translation of the intended curriculum. Although certain components of the teachers' belief structures facilitated implementation, on the whole the teachers significantly altered the curriculum to be more congruous with their existing belief structures, which were incongruous with the underlying philosophy of the intended curriculum.

Framed in terms of cultural myths, Kenneth Tobin and Campbell McRobbie (1996) examined the beliefs about teaching and learning of an experienced chemistry teacher, Jacobs. Jacobs made sense of his teaching based on four cultural myths concerning transmission of knowledge, efficiency, rigor in the curriculum, and assessment. The myths related closely to one another and were grounded in two core beliefs: (a) knowledge exists separate from the knower, and (b) the teacher should have power in enacting curriculum. The myths led to classroom practices consistent with the two core beliefs but in clear contrast to the type of instruction advocated in science reform initiatives.

These studies provide examples of the influence of teachers' beliefs on their practices in the context of curriculum reform. Specifically they paint a detailed portrait of how, when teachers' beliefs are incompatible with the philosophical underpinnings and advocated practices of reform-based curricula, implementation of reform initiatives is compromised. On the other hand, since the publication of the *National Science Education Standards* (National Research Council [NRC] 1996) and the resultant shift in emphasis of science education toward more inquiry-centered classrooms, studies have emerged that show a more positive influence of teacher beliefs on the process of reform-oriented curriculum implementation. For example, in a study by Karen Levitt (2001), it was found that the majority of the 16 US elementary teachers from two school districts involved in a local systemic science education reform initiative (called ASSET) held beliefs and demonstrated practices that were consistent with recommendations for teaching and learning science as described in the *National Science Education Standards* (NRC 1996) and facilitated curriculum reform. Moreover, Levitt concluded that in the process of implementing a program of science education reform, beliefs and practices changed in a reciprocal way; that is, not only did teachers' beliefs have a positive influence on curriculum implementation, but the process of implementing the reform-based practices of the ASSET program had a positive influence on some of the teachers' espoused beliefs.

Similarly, Barbara Crawford (2007) found that the US prospective teachers in her study who exhibited the firmest beliefs aligned with a goal of engaging students in inquiry were able to enact those views in their practice, even in the face of "the rough and tumble of practice" (p. 613). She concluded that prospective teachers' belief systems, including epistemological beliefs about science, may well serve as the most critical factor influencing his or her ability and intentions to teach science as inquiry, even more influential than cultural obstacles (e.g., resistant student, mandated curriculum).

The Role of Context and Teacher Beliefs

The role of science teachers' beliefs is significant to curriculum implementation and cannot be overlooked or minimized in the process of curricular change and innovation. However, as many studies suggest, there inevitably exists contextual factors that have a mediating influence on teachers' beliefs in the process of curriculum implementation. As science education studies have documented the influence of teacher beliefs on curriculum reform, studies also have emerged that focus on the role of contextual constraints and demands on teachers' beliefs, practices, and implementation of reform-based curricula (e.g., Haney and McArthur 2002). The context of the teacher includes how the teacher perceives his/her world as well as the teaching conditions that teachers must negotiate on a daily basis. Specifically, these studies have shown that teaching practices associated with positivist/empiricist epistemologies resonate with a number of external teaching conditions that rarely challenge teachers' epistemological beliefs: strict accountability, a culture of time efficiency, mandatory curricula, state and national assessments, teacher socialization. Randy Yerrick and colleagues (1997) asserted that these external conditions may influence teachers to the point that they simply resist thinking about content and teaching in any other way. Even when teachers hold private, individual beliefs that align with constructivist-oriented epistemologies, such conditions often become the mediating factor in teachers' decision making. In these cases, teachers face a difficult conundrum in reconciling what they believe about science teaching and learning with the powerful influence of the constraints that they encountered in the school culture.

"Incongruity" Thesis

Just as there are studies that support the influence of teachers' espoused beliefs on their practices, a competing set of studies exist that demonstrate that *teachers' espoused beliefs do not necessarily influence their actions.* These studies by and large portray teachers who espouse beliefs that are congruous with philosophical underpinnings of reform but are incongruous with their observed teaching practices.

In one of the most comprehensive and long-term studies on science teacher beliefs to date, researchers from nine different US institutions in the Salish I consortium conducted a 3-year investigation of the beliefs and practices of 116 beginning teachers as related to their philosophical beliefs about teaching and their content pedagogical skills. One report from this study (Simmons et al. 1999) focused on 69 participants and showed that overall beginning teachers' espoused beliefs were incongruous with their teaching practices. Specifically, beginning teachers espoused student-centered beliefs and described their teaching practices as very student-centered. However, observational data portrayed a set of teaching practices that starkly contrasted with the teachers' beliefs.

Kang and Wallace (2004) profiled the epistemological beliefs and practices of three US experienced secondary science teachers and concluded that beliefs do not necessarily have a direct causal bearing on teachers' actions. They found that while two teachers who held naïve epistemological beliefs tended to practice in ways that resonated with those beliefs, one teacher who held sophisticated epistemological beliefs about science did not demonstrate instructional practices clearly connected to those beliefs. While the teacher espoused a view of "real science as scientists' tentative explanations validated through rigorous inquiry processes; truths of scientific explanations depend on contexts" (Kang and Wallace 2004, p. 148), he completely separated "real science" from school science and the science teaching context, and therefore did not fully apply his sophisticated epistemological beliefs to his teaching practices.

Vicente Mellado (1998) also found that there is not a clear and direct correspondence between teachers' beliefs and practices. He examined the beliefs and practices of two prospective primary teachers and two prospective secondary teachers who completed their studies at the University Extremadura in Badajoz, Spain. Mellado found that while their espoused beliefs reflected an apparent constructivist orientation toward learning, their observed teaching practices reflected little to no correspondence to these beliefs. In one of the cases in particular, the teacher, Ana, espoused beliefs that were not completely recognized in practice predominantly because her espoused beliefs were epistemologically naïve.

The underdeveloped, naïve nature of teachers' beliefs is a recurring theme in science education literature on prospective teachers' beliefs, particularly in those who espouse beliefs regarding a discovery approach to students' ideas. These teachers tend to believe that children's ideas are valuable simply because they are the children's ideas (Mellado 1998). When prospective teachers espouse beliefs about the active learner roles in which students express their ideas, their beliefs often lacked the attention to the role of students' ideas in reasoning, explaining, and making sense of science phenomena. For example, in a recent study by Yesdan Boz and Esen Uzuntiryaki (2006), 12 Turkish prospective secondary teachers espoused beliefs about chemistry teaching and learning that included a belief that group work and interaction among students in chemistry lessons should involve students in the learning process. However, when asked to describe specifically how students would be involved in the learning process, the teachers' explanations were limited to vague statements about understanding what students think, allowing students to express their views, and learning from each other.

Change in Beliefs: The Influence of Teacher Education Programs on Prospective Science Teacher Beliefs

Research has shown that prospective science teachers' beliefs are formed from years of experience as a science learner, an observer of the profession, and a participant in education courses, as well as from limited experiences as a science teaching professional (e.g., teaching in a practicum, tutoring). Through years of these experiences, prospective teachers have encountered and consumed implicit and explicit messages and images from which they form beliefs that influence their future practice – beliefs about the nature of science, how students learn, what constitutes effective science teaching, the teacher's and students' roles in the science classroom and various other aspects of schooling (Eick and Reed 2002). Prior to their teacher education, many prospective science teachers often have not been exposed to more contemporary educational theory that promotes a view of learning as generative and revisionary in nature. However, as teachers have been entering preparation programs over the last two decades, they have been confronting their largely empiricist, transmission, and absorptionist beliefs vis-à-vis constructivist epistemology and teaching. Nonetheless, conflicting findings have been reported about the influence that experiences in teacher education programs have on teacher thinking and learning to teach science.

For example, in one of a set of studies conducted by a group from the University of Wisconsin-Madison (UWM), Helen Meyer and colleagues (1999) examined prospective elementary teachers' beliefs about science, learning science, and teaching science, and how these beliefs developed over the course of a teacher preparation program that emphasized conceptual change teaching. The three teachers profiled in the study entered the program espousing beliefs about learning in which the learners' role was to receive knowledge presented from other sources. All three teachers made progress in revising their beliefs in the direction of the goals of the program.

However, their progress was dependent upon their individual beliefs about science and science learning. Furthermore, the progress that they made in developing practices that aligned with the program was found to differ among the prospective teachers. In one case, the teacher was hampered by her lack of knowledge of alternative teaching approaches and not having a solid content knowledge base. In another case, there was a mismatch between the teachers' espoused beliefs and classroom practices that reflected her ongoing struggle during the year as she reconciled the tensions between her beliefs and the reality of her teaching.

In another study conducted by the UWM group, John Lemberger et al. (1999) reported on three prospective secondary teachers' beliefs and practices through their teacher preparation program. The prospective secondary teachers entered the program with positivist beliefs about science and transmission beliefs about science teaching and learning. In addition, they believed that the overriding responsibility of the teacher was to ensure that students left instruction with the correct scientific answer, a belief that aligned with their empiricist view of science as an authoritative set of facts. These initial views of teaching science remained a "high-status" conception for the teacher throughout the program. Nonetheless, as the teachers completed the teacher education program, they demonstrated elements of more student-centered beliefs about science teaching and learning. The researchers noted that as teachers exited the preparation program, they were still struggling with the conflict between positivist beliefs about knowledge and transmission beliefs about teaching versus conceptual change teaching.

Keith Skamp and Andrea Mueller (2001) found that 12 Canadian preservice science teachers' beliefs about learning science at the entry of the program were characteristic of discovery learning and process teaching approaches. That is, they believed that students learn by engaging in science instruction, but the nature of that engagement was often limited to working with physical manipulatives ("hands-on" science). Handling concrete materials, in turn, would lead to something that the student would discover and remember. Furthermore, despite the constructivism emphasis of their 2-year postgraduate science teacher education program, the prospective teachers did not change their discovery learning framework of beliefs about science teaching and how students learn, and even slightly expanded those beliefs. The researchers noted that these findings were similar to an earlier study of the beliefs of nine Australian student teachers conducted by Skamp (1995). While student teachers indicated that additional beliefs about effective primary science teaching emerged, they overall maintained their entry beliefs about teaching and learning.

The Maryland Collaborative for Teacher Preparation (MCTP) is an example of a program that reported a significant positive influence on prospective teachers' beliefs about science and science teaching. In a study conducted by Randy McGinnis and colleagues (2002), the attitudes toward and beliefs about mathematics and science of more than 200 prospective teachers were traced over a 2.5-year period. The landscape of teachers' beliefs that evolved over the MCTP program showed that their beliefs moved substantially and significantly in the direction compatible with the guiding principles of the MCTP program, including "mathematics and science for all, the use of cooperative learning, the use of technology to enhance instruction, the fundamental importance of problem solving, and the view that the disciplines are human endeavors open to revision" (p. 719).

Change in Beliefs: The Influence of Professional Development on Teacher Beliefs

The slow pace of reform in science education has been attributed to a fundamental characteristic of teacher beliefs: beliefs are stable and highly resistant to change (Haney et al. 1996). Numerous studies have demonstrated that despite a range of professional development experience – from short summer courses to intense and sustained professional development efforts – the process of facilitating revision and change of teacher beliefs and practices is complex and not always successful. For example, in a study by Yerrick et al. (1997), teachers overall did not shift in their beliefs about the nature of scientific knowledge, teaching, and assessment, despite participating in a professional development program whose goals aligned with tenets of reform. Instead, teachers assimilated "new messages" into their initial set of fundamental beliefs. The researchers concluded that the teachers' "unshakable" beliefs kept them from understanding the merit of present-day scientific inquiry and realizing the tenets of reform.

The difficult process of facilitating teachers' change in beliefs and practices through professional development also was reflected in a study by Jari Lavonen and colleagues (2004). Finnish physics teachers who participated in a 1.5-year In-service Training for Physics Teachers (ITPT) professional development program aimed at enhancing their use of laboratory experiments developed an improved awareness of the goals of classroom experiments. In addition, the teachers reported more attention to using experiments consciously to help students construct meaning. However, while their beliefs seemed to move toward those advocated by the ITPT program, only approximately 20% of the participants enhanced their use of experiments in conjunction with the goals of the program.

Several studies have shown that specific design elements of professional development programs in science education are crucial in facilitating teachers' changes in beliefs and practices. For example, Julie Luft and colleagues (2003) examined teacher beliefs in the context of variations on traditional in-service professional development programs. Beginning secondary science teachers who participated in a *science-focused* support program held more conceptual and constructivist beliefs about student learning, implemented more inquiry-based or students-centered lessons, and felt fewer constraints in their teaching than did teachers in no induction program or a general induction program. These findings support teacher education research that has shown that subject matter focus and sustained contact are necessary for effective professional development.

Mentoring and coaching relationships have been shown to significantly and successfully facilitate the revision and refinement of science teachers' beliefs and practices, particularly in the context of participation in studies in which the teacher and science educator were coresearchers. For example when beginning teachers participated as coresearchers in studies with Ken Tobin, they refined their beliefs and practices through iterative cycles of analysis and reflection upon what happened in their respective classrooms and ways to improve student learning (e.g., Tobin 1993). In these studies, metaphors served as an organizer for beliefs and practices and became a critical tool in facilitating the teachers' change in beliefs. While such a process was difficult, labor-intensive, and required considerable reflection on practice, the teachers noted that they became empowered and accountable for their classroom practice in the process of educational reform.

Complexity of Beliefs

Within the last decade an increasing number of studies have surfaced that focus on the complexity of beliefs. The major assertion of these studies is that when beliefs and practices are found to be incongruous, the relationship between beliefs and practices may not be so simple. These studies have demonstrated various aspects of the complexity – beliefs as clustered, nested, and competing.

Derek Cheung and Pun-Hon Ng (2000) studied the curriculum beliefs of 810 integrated science, chemistry, physics, and biology teachers in Hong Kong. One of the significant findings reported in the study indicated that science teachers' beliefs about curriculum design were held in clusters and had a hierarchical structure. They found that five curriculum orientations (academic, cognitive process, society-centered, humanistic, and technological) clustered together to form a superordinate curriculum meta-orientation. Hence, it was possible for a science teacher to hold several competing orientations. Furthermore, they asserted that the clustering effect may explain the varying degrees of incongruity between teachers' beliefs and practices seen in research.

The complexity of teachers' beliefs has also been characterized in terms of "nestedness." In an interview study of 37 Taiwanese teachers, Chin-Chung Tsai (2002) investigated teachers' espoused beliefs about science teaching, learning science, and the nature of science as traditional, process, or constructivist. He found that most science teachers held traditional beliefs across the three belief categories. Only two of the 37 teachers espoused totally divergent beliefs. Furthermore, more than half of the teachers demonstrated close alignment between their beliefs about science teaching, learning science, and the nature of science, forming a belief system that Tsai termed "nested epistemologies." Similarly, Stephen Waters-Adams (2006) found that the complex relationship among sets of beliefs influenced four English primary teachers' practices, specifically the nested nature of teachers' espoused beliefs about the nature of science and their beliefs about education, teaching, and learning.

While nested epistemologies found in Tsai's and Waters-Adams' studies tended to be experienced teachers, Lynn Bryan (2003) found substantial nesting characteristics in the belief profile of a US prospective elementary teacher. The prospective teacher held a highly complex set of beliefs that included foundational beliefs and dualistic beliefs. One nest of beliefs was based on her vision of science teaching and reflected a student-centered, discovery approach to teaching. This nest consisted of espoused beliefs to which she developed a commitment in her teacher preparation course, but with which she had very little experience enacting in a classroom. The other nest of beliefs was well-developed, supported by years of educational experiences, and reflected a transmission view of teaching and learning. This nest of beliefs had a stronger influence on her practice during student teaching as it was resonant with her foundational beliefs about the nature of science and control in the classroom and created a strong, consistent, and self-reinforcing belief system. The nested and competing nature of beliefs described in this and other studies is resonant with psychology literature in that beliefs within a system that are incompatible or inconsistent with one another may remain so, as long as they are not examined against one another (Rokeach 1968).

Direction for Future Research

Upon reflecting on the international representation of the studies in this chapter, it was somewhat surprising that very few studies addressed the sociocultural dimensions of science teacher beliefs. As the world's population becomes more globalized and populations become more mobile, the demographics of today's classrooms are changing. Classrooms around the world are becoming more diverse. Hence, it seems incumbent upon science educators to consider the sociocultural dimensions of teacher beliefs, particularly as they come to bear on equitable science instruction, or "science for all." For example, what is the relationship between teacher beliefs about culturally diverse students, teachers' decisions and actions, and equitable science learning opportunities for students? What science teacher beliefs are likely to predict successful teaching of culturally diverse students? How do science educators facilitate teachers' change or refinement in beliefs in ways that will assist them in developing science curricula that empowers students from culturally diverse backgrounds?

One series of studies by Okhee Lee and colleagues (e.g., Lee et al. 2007) has been examining such questions, in particular elementary school teachers' beliefs and practices regarding science instruction in linguistically and culturally diverse classrooms. Overall these studies showed that changing teachers' beliefs and practices to incorporate students' cultural and linguistic experiences into science instruction is a gradual and challenging process – regardless of whether or not the teachers shared elements of their students' language and culture. Furthermore, these studies illustrate the complex and nuanced relationships among culture, language, and science learning.

Another line of research for the field of science education to consider relates to the influences of teachers' personal cultural beliefs (e.g., beliefs related to the social norms, customs, values, and social practices associated with a group of people) on science teaching decisions and actions. One example of such a study is Ping Wang's (2004) investigation of the influence of traditional Chinese cultural beliefs on science teachers' assessment practices. Wang described how in a long course of historical development, the Chinese people have developed several cultural bond characteristics. He illustrated through an analysis of multiple cases how the unique concept of "face" and keeping face in the Chinese culture influenced teachers' decisions to implement certain assessment practices. He discussed how cultural beliefs strongly motivated the decisions and practices of the Chinese teachers, even in the era of science education reform:

> Chinese slangs, "Chu Tou De Chuan Zi Xian Lan" (the rafters that jut out rot first—one who wants to be in the fore will get into trouble) and "Shu Da Zhao Feng" (a tall tree catches the wind—a person in a high position is liable to be attacked), to name but a few, reflect the characteristic of Chinese people to fit into the crowd…. A practical representation of the above characteristics in Chinese school system is a collective mode of teaching. [Teachers] are expected to teach with the same approach and at the same pace. (pp. 103–104)

Unquestionably, all cultures have some characteristics and beliefs that distinguish them from others. An interesting and necessary line of research entails uncovering the tacit and taken-for-granted sociocultural aspects of teachers' beliefs and development of knowledge for teaching science. Specifically, what is the relationship between teachers' culture, beliefs, and practices? What are the implications of this relationship on teacher learning?

Concluding Remarks

If teachers' are expected to revise and refine their beliefs and practices, science education instruction must provide ample opportunities for teachers to articulate and confront beliefs vis-à-vis their practices and the philosophical underpinnings of reform. Both teacher educators and students of teaching need to view teaching as a process of inquiry, and view tensions as a necessary stimulus for developing professional knowledge about teaching and learning. Adopting the view that learning to teach science is analogous in many ways to learning science means taking into account that (a) teachers should engage in experiences that contribute to constructing their knowledge about teaching and learning, rather than passively receiving and accepting information; and (b) revising and refining beliefs and practices entails reflection in and on practice (Schön 1983). Science teacher educators must also recognize not only that teachers may hold beliefs that are incongruous with the philosophical underpinnings of reform initiatives, but also that they may not have well-developed knowledge to enact those beliefs (i.e., knowledge of how to use the approaches advocated in reform), as they may not have learned science themselves through the use of instructional approaches guided by these learning principles. Hence, it is essential that as science teacher educators design professional development experiences, they take into account that teachers may need to reflectively consider or reconsider principles of learning derived from research, as well as how to facilitate learning in their classrooms based on these principles.

Science teacher educators also must keep in mind that experience for the sake of experience, is not in and of itself educational. Research has shown the most educative experiences are those that provide substantial support of teacher learning: ongoing assessment and evaluation, time and opportunities for reflection, administrative and community support, and opportunities for observing and being observed. The goal of science teacher education should be to facilitate teachers' disposition to inquiry and to systematically reflect upon their beliefs, practices, and developing knowledge. Teachers at all stages of their career trajectory must continue to challenge and refine their ideas about teaching and learning science and learn how to learn from experience. Learning to observe and analyze teaching; learning to isolate, frame, and reframe problems of practice; and learning to take action and interpret that action are skills that take time and practice to develop. Moreover, teachers' interpretations are fundamental to the process. Rather than confronting teachers with alternative conceptions and administering prescriptions for improving practice, teachers should share responsibility in their learning.

Finally, the complexity studies reviewed suggest that science teacher educators should consider addressing the system of beliefs, rather than targeting individual beliefs. Reform efforts advocate teaching science such that there is a weaving of science knowledge, the nature of science, and science processes in science instruction. Likewise, teacher educators should consider targeting prospective teachers' systems of beliefs about science knowledge, the nature of science, and science processes.

Science education reform in countries around the world advocates a view of learning science that places more of an emphasis on understanding scientific concepts and developing abilities of inquiry, using evidence and strategies for developing or revising an explanation, attending to students' active engagement and learning needs, and acknowledging that students perceive their world through the knowledge and beliefs that they hold. This view of the science classroom means not simply new sets of teacher practices, but a revised and contemporary way of thinking about science and the teaching and learning of science. The success of these reforms indisputably depends upon science teachers' capacity to integrate the epistemology and practices of reform with their beliefs and extant practices. Whether it is a process of refinement or complete revision, it is a matter of learning. Research on science learning tells us that learning begins with the existing beliefs and knowledge of learners. If gains are to be made in terms of reforming science teaching, then teacher educators must tailor instruction to address the beliefs and knowledge of those who are expected to enact the changes. Ignoring or marginalizing the role of teachers' beliefs in the process of improving science education is essentially the same as ignoring the role of students' existing beliefs and knowledge in the process of learning science.

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Part IV
Equity and Social Justice

Chapter 34
Still Part of the Conversation: Gender Issues in Science Education

Kathryn Scantlebury

Recent studies and policies suggest that teachers, researchers, students, parents, and policymakers no longer need to consider gender as one of the constructs when examining issues in science education such as students' learning, achievement, attitudes, participation, career trajectories, teachers' perceptions and practices, curriculum, and assessment. For example, in the USA, the major policy impacting K–12 education in the twenty-first century, the *No Child Left Behind* act, requires accountability for students' achievement in mathematics, reading and language arts, social studies, and science disaggregated by race and students with learning disabilities. But because the perception from policymakers and educators is that the education inequities between students attributable to gender are no longer salient, it is optional for state agencies to report achievement data by gender (Kahle 2004). Science education researchers acknowledge that studies focused on gender issues, while ignoring the possible mediation of students' ethnicity, race, religion, sexuality, and/or class, are limited and in some cases can produce misleading results. And there are few studies that have taken into consideration gender, race/ethnicity, religion, sexuality, and/or class when analyzing data and inferring conclusions (Scantlebury and Baker 2007). One reason for the disinterest in continued gender studies in science education may be because researchers have noted for several decades that the differences within a gender are larger than those that exist between genders. A study from the American Association of University Women (AAUW) reported that gender differences between girls and boys have decreased and in some subjects no longer exist. But the analyses typically do not examine students' achievement data broken out by girls' and boys' ethnicity and/or social-economic status (Corbett et al. 2008). The lack of detail in the achievement differences within and between groups of students by gender has limited researchers' understandings of the issues that mediate students' achievement, attitudes, and participation in science.

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For example, in the USA, the executive summary of the 2005 National Assessment for Educational Progress (NAEP) science results described achievement trends across the grade levels, making comparisons with 1996 and 2000, and examining differences attributable to race. There was an increase in the gap between 12th grade White and Black students. Gender was not reported in this overview chart or at the 8th grade level. At 4th grade level, there was a 4-point gap in favor of boys, but this finding has little practical significance. For 12th grade students, males had significantly higher scores than females, and overall girls' achievement results were the same in 2005 as they were in 1996 and 2000. In the same time period, males' achievement declined. However, the report did not provide further analyses of the factors influencing students' achievement. Is there a difference between the achievement of Black, Latina, Asian, and White girls and if so why? If there are achievement differences between these groups, are those differences influenced by socioeconomic status? Do male and female students within racial, socioeconomic, and religious groups have similar science achievement, attitudes, and participation rates?

The latest study from AAUW focused on the participation of women in science, technology, engineering, and mathematics (Hill et al. 2010). Three major themes emerged from the report. First, there remains a strong perception that males are inherently better at mathematics, and thus more likely to succeed in science and mathematics than women. Based on this perception, US society attributes gender differences in students' participation to their cognitive abilities ignoring the influence of the sociocultural context. However, the report noted that the cultural context accounted for the changes in girls' mathematics participation over the past three decades. Second, girls and women are not interested in science. Third, balancing work and life demands differentially impacts females and males, and women are more likely to leave, or underachieve in science than their male peers (Hill et al. 2010). The report did provide participation and achievement data for various racial groups; students' socioeconomic status was not included in the analysis. And the authors noted that much of the data and studies reported were based upon the experiences of White females. Further research is needed; for example, do the perceptions about students' ability in mathematics change because of race, socioeconomic status, and other social factors? Are our perceptions that African-American, Latina, and Asian girls will have similar success in science? Are there differences in students' interest in science because of race, socioeconomic status, and other social factors? Further, the report showed how few women from African-American and Latina cultural backgrounds pursue and succeed in science; what are the barriers these females face? What are the external, nonwork-related factors that influence women to leave science careers or career paths? What work-related factors contribute to women leaving science? How do the factors differentially impact women from different racial, socioeconomic, religious, and language groups?

In addition to gender researchers ignoring critical questions about the influences that students' gender, ethnicity, race, religion, sexuality, and/or class may have on their learning, achievement, participation, and persistence in science, there are also critical research areas in science education that have ignored, or have not seriously addressed, gender issues. Feminist research has clearly documented the salience of gender, along with other social factors such as race, socioeconomic class, religion, language proficiency, and/or sexuality, yet these factors are not considered in most conceptual change research on how students learn science (Scantlebury and Martin 2010). Conceptual change research has dominated science education journals for the past three decades. However, there are few studies that address how females and males may come to know science differently because of their experiences, let alone consider how other sociocultural factors may combine with gender to ameliorate students' in- and out-of-school experiences.

Within gender studies researchers have often missed the opportunity to further explore nuances. For example, Hanson's study (2009) focuses on African-American girls and science but did not examine other sociocultural factors; the girls were treated as a homogeneous group. While this study provided a counterbalance to the preponderance of research focused on White girls, the opportunity for a deeper examination of the science experiences of African-American girls in various cultural contexts – urban, suburban, and public or private schools – was lost. This is particularly unfortunate if one considers the differential impact that African-American culture has on girls and boys. For example, the role of "othermother" (being responsible for child care for nonbiological children or children from the extended family) mediated girls' continued access to education and their practices within the classroom (Scantlebury 2007). African-American girls have positive attitudes toward science, learn self-reliance, and attain a level of independence that their Latina and White peers do not (Hanson 2009). In contrast, urban African-American boys have lower academic aspirations and higher truancy rates compared with their sisters.

While African-American girls may have higher education aspirations compared to their male peers, their science achievement is below girls from other racial groups. Yet gender research has yet to explore why girls' and boys' socioeconomic status has more influence on their achievement than their race and the role of gender in that finding. For example, an examination of students' achievement on NAEP reading and mathematics showed that girls had higher scores in reading than boys, and boys from low-income families had the lowest reading scores. Similarly in mathematics, boys outscored girls but girls in a high socioeconomic bracket outperformed boys from a low socioeconomic group. But we do not have studies examining girls' and boys' science achievement that consider race along with socioeconomic status. Future research could examine if there are any differences between the science (or mathematics) achievement of high-income African-American, Latina, Asian, and White girls and boys. Other questions may include: Does the low, middle, or high socioeconomic status of African-American, Latina, Asian, and White girls and boys differentially impact their science (or mathematics) achievement? If there are different achievement patterns associated with students' socioeconomic status, race, and/or gender, are these patterns consistent in different cultural settings?

Review of Gender Issues in Science Education

In the mid-1990s, Jane Kahle and Judith Meece (1994) critiqued the deficit view of girls and women that initially framed research in gender issues. Intervention programs focused on "fixing" girls, rather than critiquing science curriculum or science itself. Kahle and Meece recommended that researchers focus on sociocultural aspects of learning. In particular, they noted the role of teachers with regards to encouraging and engaging students in science through their pedagogical practices and curricular choices. Dale Baker (1998) reiterated that view and also included a historical perspective to the low number of women and minorities in science compared with White males, citing the influence of home, how cultural issues can act as barriers to females' science participation, and the impact policy could have on those barriers. A decade later, Kathryn Scantlebury and Dale Baker (2007) noted that science education research had examined broader gender issues, including how heteronormativity impacted science curriculum (i.e., textbooks) and the use of queer theory to critique science teacher education. But overall, the field had produced few studies that examined issues of gender with race, ethnicity, class, religion, and/or sexuality. Further, studies that focused on teachers' attitudes toward gender roles and practices were still needed, as classroom-based research continued to document a range of micro-inequities between girls and boys ranging from access to human (i.e., teacher) and physical resources (equipment), to perceived learners', parents' and teachers' expectations of students' abilities in science which impacted students' science self-esteem and self-efficacy.

Recently, Jennie Brotman and Felicia Moore (2008) classified published science education articles on gender issues for K–12 from 1996 through to 2006 as having a focus on equity and access, curriculum and pedagogy, reconstructing the nature and culture of science or identity. In equity and access, they noted that girls prefer biological sciences and boys continue to be more interested in physical sciences than girls. This issue regarding students' science preferences has remained consistent for over 40 years of research in science education. Researchers have suggested that girls relate better to biological topics, while the cultural influences on boys emphasize more aggressive interests. That is, boys are encouraged to explore and play games that are more aligned with physical sciences (e.g., shooting firearms, explosions that involve loud noises, and other extraneous energy transformations). Students have strong stereotypes that view the physical sciences as masculine and the biological sciences as more feminine. Boys receive more out of school science experiences than girls. Girls' interests in science begin to decline during middle school. However, we do not understand how these general trends are nuanced by race and other sociocultural factors. Thus, science education researchers could begin to examine these data from multiple perspectives.

Brotman and Moore (2008) found that curriculum that builds from students' interests and preferences engaged more students. They also classified researchers' approaches to revising science curriculum as either girl-friendly, gender-balanced, and/or gender-inclusive. Although these terms have slightly different meanings and interpretations, girl-friendly science curriculum evolved in the 1980s in response to various feminist studies of science education. Researchers proposed that science curricula failed to engage girls' interests and suggested revised, "girl-friendly" science curricula. Girl-friendly curricula introduced science topics that girls either stated that they wished to learn or that researchers and teachers thought would interest girls. A key aspect of "girl-friendly" science curricula included the contributions of women to science. Gender-inclusive curriculum attempted to include the interests of girls and boys. Another aspect they highlighted was the importance of engaging teachers with a critical review of the curriculum, and the pedagogy used – especially when these two aspects could reinforce the marginalization of students from under-represented groups, and girls in particular, from science. Their final theme looked at the role of gender in students' identity, especially a science identity. In particular, this area of research has moved away from analyzing data from a female/male binary perspective and argued that others' aspects also shape students' identity – such as, racial background, socioeconomic status, and/or religious affiliation.

Angela Calabrese Barton (2008) introduced three concepts to define critical science agency. Those concepts are intersectionality, counter-knowledge, and solidarity. Calabrese Barton (2008) used examples from ecological feminism to describe how science education could broaden its ideology to produce an education that would resonate with students and provide opportunities for them to embody science as part of their identity. Intersectionality acknowledges the multiple dimensions of one's identity and the complexity of social relations and establishes that women's experiences are multilayered, contextual, and overlapping, and thus subject to society's hegemonic forces and power dynamics. Counter-knowledge expands on those ideas by foregrounding the knowledge and experiences of those who have lived on society's margins. In ecological feminism, women through their activism challenged to improve living conditions for their families and communities. Through environmental activism, groups of women demonstrated solidarity in their voicing of concerns for the health and well-being of their families and their commitment to improving the community's living conditions. Overall, gender research in science education has yet to utilize intersectionality and researchers could explore its potential for providing the new insights into how gender may shape science education students' science education. Further, we could examine how the students typically disenfranchised by science education could become engaged through curriculum focused on local environmental issues. For example, students could become engaged in local environmental impact studies, where they could collect and analyze data about water and air quality, levels of pollutants, and/or biotic and abiotic factors that may influence the quality of their lives and those of their community.

Focusing their discussion on gender issues in the USA, Jasna Jovanovic and Ruchi Bhanot (2008) noted that differing gendered expectations for girls by their parents, teachers, peers, and themselves continue to limit girls' opportunities to learn and succeed in science. They suggested that societies are moving away from gender stereotyping; however, the perception of science as a masculine endeavor has remained a strong image for several centuries. One future direction for gender research in science education could examine why science's masculine hegemonic structures have remained so entrenched.

While the number of girls and women that are participating in science has increased over the past three decades, recent research suggested that student attitudes and perceived value of the subject have remained static and in most countries students' interests in science continue to decline (PISA, Organization for Economic Coordination and Development, OCED 2009). The next section addresses gender issues in science student achievement and attitudes toward science as reported by two international studies, the Program of International Student Assessment (OCED 2009) and the Third International Mathematics and Science Study (TIMSS) (Gonzales et al. 2008).

Students' Achievement and Attitudes

PISA (OCED 2009) provided three reasons for studying gender differences – to identify inequalities, to examine student performance, and to increase an understanding of how students learn. The 2009 report focused on examining gender differences across various subjects for 15-year-old students and found small gender differences in students' science achievement. The three areas on the PISA test were *identifying scientific issues, explaining phenomena scientifically*, and *using scientific evidence*. Males scored better than females on *explaining phenomena scientifically.* Females had higher scores than males on *identifying scientific issues.* Research conducted in science classrooms may offer some explanation of these results. Boys typically offer, and are called upon to answer, questions more often than girls (Scantlebury and Baker 2007). Also, teachers tend to ask boys more conceptually challenging questions. Thus, boys may have more experience explaining scientific phenomena. Girls could identify and understand the features of a scientific investigation that may rely on a student's reading comprehension. Also, their ability to identify variables and identify what other information may also relate to their language skills. Girls have higher reading and comprehension skills than boys. In physical and earth science, males performed higher than females. This pattern has remained consistent throughout the decades of gender studies, and has been explained by girls' preferences for learning about humans and other living things rather than physical science phenomena.

Achievement scores had minimal gender differences and different outcomes depending upon the country. Turkish and Greek girls scored higher than boys, while boys from the UK, Luxembourg, Denmark, the Netherlands, Mexico, and Switzerland scored higher than their female peers. The OCED report categorized countries into one of three groups. First, there were insignificant gender differences in science on the three scales, *identifying scientific issues, explaining phenomena scientifically*, and *using scientific evidence*, and this pattern held for school-level analyses. Thus, regardless of students' geographic location (rural, urban, or suburban) or school size, female and male students performed at the same level on the science scales. A second group of countries had insignificant gender differences at the national level but differences between girls and boys occurred at the school level. OECD (2009) further examined this pattern and found that in Australian and Belgian schools where students had a higher socioeconomic status, boys were more likely to outperform girls. But in Austria, gender differences decreased between students of higher economic status. Also boys from lower socioeconomic standing were more likely than their peers or girls to drop out of school. These variances on student performance have policy implications for school funding and the practices that may reduce gender differences in one country or group of students may not be successful in other settings. Possibly, in Australia and Belgium, students in the higher socioeconomic group might have a stereotyped attitude that may influence student achievement: that science is more suitable for boys than girls. A third group of countries, namely, UK, Luxembourg and Denmark, had significant gender differences overall and at the school level. These results in achievement may be connected to students' attitudes toward science because in those countries, males had more positive attitudes toward science than their female peers (OECD 2009). These results do not provide insights into whether there are gender differences in students' achievement that relate to socioeconomic status and school. Identifying the reasons for these different patterns is another area where gender researchers could conduct studies.

Two attitudinal areas were tested: *interest in science* and *support for scientific enquiry*. PISA used effect sizes to examine students' attitudes toward science on subscales that included *self-efficacy, self-concept, interest in science, enjoyment of science, instrumental motivation to learn science, career intentions, awareness of environmental issues, optimism regarding environmental issues*, and *responsibility for sustainable development.* Males scored higher than females on the *self-efficacy* scale in Japan, the Netherlands, Iceland, Korea, and Taiwan. Previous gender research in Japan found that males studying science in high school and college viewed females as having less science ability than males and science as an inappropriate career for women. Female Japanese students reported that women had the ability, confidence, and interest but there were structural barriers to their participation in science (Scantlebury et al. 2007).

In a majority of the countries there were no gender differences on the *self-concept, interest in science, enjoyment of science*, and *instrumental motivation to learn science* subscales. However, there were slight gender differences in favor of males on *the intent to have a career in science*. When asked about their future careers in science, 15-year-old girls predicted they would become involved with nursing, but only 2% of girls aspired to a career in computing. For countries who are concerned with the numbers of students studying science at college and then continuing into science careers, the continued gender differences between high school males and females regarding pursuing a science degree poses an ongoing and long-term problem. The transition from high school to college and onto a career in science is an area where gender researchers could plan longitudinal studies to examine students' career trajectories to identify strategies for expanding students' participation in science.

The PISA study also addressed the influence of single-sex schools on students' achievement. While there were gender differences favoring males, when researchers controlled for the school's socioeconomic status single-sex versus mixed-sex schooling did not make a difference. In previous gender studies on science career trajectories, researchers documented that many women scientists had experienced a single-sex environment at some stage during their formative years. The single-sex experience could have been in formal education either in high school or college or in their personal lives through being only children or only sisters as siblings. Some researchers investigating the culture in classrooms suggested that girls would benefit by having a single-sex education experience in science and/or mathematics. But the PISA results infer that students' socioeconomic status rather than experiencing single-sex education is more likely to contribute to the differences in science achievement. Moreover, in England and Wales, girls in mixed-sex schools were as likely as their peers in single-sex schools to study physics, although girls in single-sex schools reported a stronger sense of belonging and higher self-esteem than their peers in mixed schools (Murphy and Whitelegg 2006).

The 2007 Third International Mathematics and Science Study (TIMSS) reported gender differences favoring girls at 4th and 8th grades (Martin et al. 2008). Fourth grade girls scored higher on reasoning, physical sciences, and life science but boys performed better on earth science questions. At the 8th grade girls had higher scores in biology and chemistry, and the three cognitive domains of *knowing, applying*, and *reasoning*, while boys scored higher in physics. In 4th, for students with a high self-confidence, girls' confidence was significantly higher than their male peers. The reverse was the case for students with lower self-confidence; girls in this group had a lower self-confidence in science compared to boys. In general, girls receive higher grades in school than boys, as they perceive education as an opportunity. While low-achieving boys, especially those from African-American and Latino backgrounds are more likely to drop out of school, and have less interest in their grades. The different results regarding gender differences from the TIMSS and PISA studies may in part be attributable to the different test styles. TIMMS emphasizes more factual and less interpretive assessments (Kahle 2004). PISA questions are placed within a context, which is preferred by girls. There is also more reading required in the PISA assessments, and as a group girls score higher on reading tests than boys.

There remains a consistent pattern regarding gender differences in students' attitudes toward science, whether the studies are conducted at international, national, regional, or local levels. Attitudes toward science decline for males and females as they remain in school; however, the decline is greater for girls than for boys. If high school girls are educated about discriminatory practices, their self-efficacy and attitudes toward the relevance of science increases; however, their interest in the subject did not increase (Weisgram and Bigler 2007). In particular, students report little interest in physics and girls cite its lack of relevance to their lives (Murphy and Whitelegg 2006). While a group of US female students reported that studying high school physics enhanced their college applications, but they had little interest in the subject (Carlone 2004).

A Hong Kong study examined the interaction effects of grade level and gender on students' attitudes toward chemistry on four subscales: (1) *theoretical chemistry lessons*, (2) *laboratory classes*, (3) *importance or usefulness of chemistry*, and

(4) *behaviors toward learning chemistry*. Significant single and interaction effects were found for gender and grade level. Males had a more positive attitude than females toward theoretical chemistry lessons in lower high school grades. And while males' attitudes on this subscale declined during high school, girls' attitudes improved. Males' attitudes towards lab work declined over their high school years, thus teachers may want to use different pedagogical approaches to maintain girls' and boys' interests in chemistry (Cheung 2009).

Science's perceived lack of relevance to females' lives also remains a reason why women choose not to participate in science at the tertiary education level. For example, undergraduate women of color reported that they disliked large lecture classes, asking and answering questions in class, and engaging in research as undergraduates. Moreover, this study identified that these female students had a negative response to the representation of science as a meritocracy uninfluenced by gender, ethnicity, or race and the presentation of college level science as decontextualized (Johnson 2007).

For the past 30 years, researchers have examined gender differences in students' science achievement, attitudes, and career trajectories in science. Small gender differences exist which may be attributable to students' classroom experiences. However, OECD's study found that gender differences in science achievement varied depending upon the country, the type of school students attended and students' socioeconomic status. The report did not examine these results by students' race. Researchers could begin to examine why there is variance in the gender differences in science depending upon country. In particular, what are the practices and policies in countries where there are no gender differences? Does this pattern hold if achievement and participation data are examined by students' gender, race, socioeconomic status, and other cultural factors?

Restructuring Science Education for Inclusivity

The research provides examples of successful instances when students, and in particular girls, become engaged with, and enjoy science. When ethnically and linguistically diverse, low socioeconomic kindergarten students participated in a 5- or 10-week science program that used inquiry, they had more motivation than a comparison group of students not involved with the program. More importantly, there were no gender differences for the project's students but in the comparative group kindergarten boys liked science more than their female peers (Patrick et al. 2009).

Middle school is a critical time for students because their attitudes toward school and in particular science decline, often along with achievement. Several classroom studies have noted the importance of generating hybrid spaces for girls to construct their science identities (e.g., Calabrese Barton & Tan 2008). When given the opportunity, urban Latina girls produced scientific artifacts such as songs, puppets, posters, and magnets through their ability to incorporate school science into their funds of knowledge. Through these experiences the girls played with their identities in a lighthearted manner that reflected their enjoyment and engagement with science and began negotiating their science roles. These practices formed a third space in which, over time the girls reconstructed their identities to include being a "scientist."

Another strategy that teachers are using to enhance students' ability to form science identities is through the introduction of cogenerative dialogues (cogens). Teachers and students have used cogens as a research and pedagogical tool in urban settings to understand the local cultures of their science classes (e.g., Bayne 2008). "Girls only" cogens with urban African-American girls resulted in the young women restructuring their teacher's perceptions of what it means to "do science," and changing her teaching practices to align with the girls' learning needs and preferences. The girls' science practices began to reflect a hybridity of gender schema that generated science identities, and also utilized cultural practices such as "othermothering" to care for and engage each other in science (Scantlebury 2007).

In another study, girls involved in an after-school science program showed a hybridity of practices (Rahm 2008). Similar to the girls who engaged in cogens together, Sabrina and Tehara used their female friendships as an avenue to construct a hybrid identity that incorporated images of themselves as people who learned, did, valued, and owned science. Findings from this research demonstrate that the informal setting can provide the space and opportunity for students who had previously never constructed "being a scientist" as part of their identities to develop a sense of achievement and science competence and knowledge through the completion of research on topics of their own choosing. The girls in the after-school program constructed their learning space, as did the girls who participated in cogens. By working in a hybrid space to construct their science identities, the girls produced a set of practices and schema that reflected those of "scientist."

Teachers' Gendered Perspectives and Strategies

There are few gender studies that examine science teacher background, attitudes, practices, and career trajectories. However, Shwu-Yong Huang and Barry Fraser (2009) reported gender differences between 818 Taiwanese female and male science teachers' perceptions of the school environment using a survey instrument (STSEQ) with nine subscales*:* Teacher–Student Relations, Collegiality, Principal Leadership, Professional Interest, Gender Equity, Innovation, Resources and Equipment, Staff Freedom, and Work Pressure. Female teachers had more positive attitudes than their male colleagues on Collegiality, Professional Interest, and Gender Equity subscales. While male teachers had a significantly higher score on Principal Leadership and Staff Freedom compared with their female peers. There was a significant difference for the effect size between the two groups on *Work Pressure*, and teachers' gender, school level, subject taught, and the number of years of teaching at current school contributed to these results. Women teachers felt more pressured to complete their work than their male colleagues, but they had more positive attitudes toward their professional relationships. However, a critical finding in the study is of concern to gender researchers, namely, that male science teachers reported that science is a subject more for boys than girls and that these teachers reportedly gave boys more encouragement in science. Female science teachers viewed the subject as equally important for both student groups.

Smaller-scale studies have used qualitative approaches to examine teachers' attitudes toward gender equity. A consequence of the policymakers and recent documents in science education ignoring gender, is that teachers who are in primary positions to challenge and change inequities no longer view equity as it pertains to gender as an issue. Working with a group of 15 science teachers using a case study approach, Kristine Andersson et al. (2009) found that introducing gender theory as the lens for interpreting the classroom events allowed teachers to deepen their reasoning and produce new interpretations of the impact of gender stereotypes on their teaching and students' science participation. The study did not extend to exploring the impact of gender theory on teachers' practices and this is another avenue where the research could emerge.

When examining a female science teacher's pedagogical practices, Maria Zapata and Alejandro Gallard (2007) uncovered tensions for the teacher between her views about science, the production of knowledge, and her pedagogical practices. The teacher in their study, Laura, noted she left the girls in her class to engage with science while she managed her male students. However, the girls could possibly interpret this action as their teacher having less confidence in their science ability than the boys. Laura's unconscious practices toward her female and male students reinforced cultural norms regarding gender stereotypes in students' academic abilities, attitudes, and behaviors.

These studies have highlighted teachers' perspectives and attitudes about gender issues in science education impact their practices and interactions with their students. Moreover, these studies emphasize the need for further research to examine the interplay of teachers' gender and race with those of their students. Introducing teachers to gender theory and also engaging them with the generation of local theory through the use of cogens are possible approaches to meet these challenges. Additionally, researchers and teachers could analyze video of classroom dynamics to uncover unconscious practices that lead to inequities in science teaching (see Martin and Siry 2011).

Rethinking Feminist Science Education

The factors identified above are symptomatic of a larger concern raised by Angela McRobbie (2008), namely that the societal gains made for/by women and girls through 30 years of activism rooted in feminism is being undone through disarticulation and displacement. Disarticulation assumes there is no longer a need for groups to focus on a particular issue and often negates the reasons for forming the group. An example of disarticulation occurs when feminism is portrayed as a movement of angry women who hate men, rather than a group using feminist theory to examine and critique societal structures that impact women and girls. A consequence of disarticulation for feminist perspectives in education is an assumption that as gender gaps in student achievement scores have decreased, "gender issues" are no longer an important issue to consider. For example, in the USA, the *No Child Left Behind* act does not require states to report test results by gender, and there is no disaggregation of data by gender and race/ethnicity. While results of international studies suggest that level of income is also an important contributor to students' achievement, those data are not gathered in the USA.

In a recent US study of over 400 projects focused on gender issues in science, technology, engineering, and mathematics funded by the National Science Foundation, researchers did not report basic demographic data such as participants' gender and race (AAUW 2004). Yet, Western education systems are becoming more diverse as immigration patterns introduce new challenges for stakeholders. For example, in the USA, English Language Learner (ELL) students, or students who are not fully proficient in English, are the fastest growing segment of students in K–12 education and the nuances that impact their learning associated with gender, race, socioeconomic status, sexuality, and religious categories have yet to be explored (Garcia et al. 2008). Another concern regarding gender studies in science education is, apart from a series of studies in the early twenty-first century, Lesbian/Gay/Bi/Transgendered (LGBT) issues have "vanished" from the published literature in science education.

Various racial and socioeconomic groups produce gender differently but as yet, science education has not fully examined how these variations in gender identities impact how students learn and participate in science or their teachers' approach science teaching and learning. Thus, the challenge remains with gender research in science education to produce studies that examine patterns and contradictions associated with gender across social categories such as race, ethnicity, social class, sexuality, and religion. How gender combines with power, identity, and intersectionality should remain part of the conversation in science education and educational researchers are to expand our knowledge about the ways in which gender impacts teaching and learning in science.

Research has shown that girls prefer life science topics, while boys focus on the physical sciences. As science research becomes more interdisciplinary, the gender divide between life and physical science may disappear, but it has been consistent for four decades, and across cultures. Yet the field has not provided definitive explanations for these patterns and studies are needed to examine how students develop their science identities and the influence sociocultural factors, in and out of school experiences, and personal expectations have on achievement, participation, and career trajectories in science.

Another consistent pattern is how teachers' attitudes and practices toward students are influenced by gender, and in this area, there are some studies that address race. The challenge for researchers is to articulate how preservice and in-service educators could improve teacher education to address these issues, given that in many Western countries the teaching populations are becoming increasingly feminized, White, and middle-class. There is a need for ongoing studies that examine gender within the context of social factors, how structures impact gendered social interactions, whether institutional and interactional levels can produce changes in gendered social contexts, and can interactions between individuals be sites for change (Deutsch 2007)? Cogens are successful in helping teachers and science educators to generate local knowledge and theories to improve teaching and learning. However, the call to action for researchers is to examine how those local examples of agency could change education and science's gendered structures because gender remains part of science education's conversation.

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Chapter 35
Respect and Science Learning

Adriane Slaton and Angela Calabrese Barton

What Is Respect and Why Is it Important?

Respect is often used, cited, and highly regarded, but there is little in the research literature describing its complexities or the relationship between how teachers and students co-construct respect in classrooms. Notions of respect are intimately connected and vital to the work done in science classrooms. With this chapter, we construct a working framework for understanding respect as a practice as well as to trouble traditional notions of respect focused on respect as static or absolute power and authority.

We put forth the idea of *practices of respect*, or context-specific actions individuals take to publicly appreciate or develop understandings of others and their value. Applying this framework of respect is important if we want to understand how and why participants seek to engage in science learning opportunities as well as to help us consider issues of identity development. With this paper, we make the case that looking at classrooms via *practices of respect* contributes to the field a new working sociocultural framework for observing science classrooms. This framework allows for understanding respect as a practice, troubling traditional notions of respect focused on respect as static or absolute power and authority. Notions of respect are intimately connected and vital to the work done in science classrooms: When teachers and students collaboratively author practices of respect, opportunities to learn are expanded for all students.

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Forms of Respect in Literature

Respect has been a part of the lexicon of educators for more than four decades. However, a close analysis of the work on respect shows several different orientations for thinking about the nature or function of respect within school settings. While earlier work tended to focus more on respect as a quality or possession, more recent work has focused on respect as dynamic and situationally contingent. It is with this latter body of literature that we consider respect more deeply. The work on respect can be grouped into two categories: Respect as commodity (something that can be earned, given, or exchanged) and respect as a relationship (something that is enacted between people to define their position vis-à-vis one another). We draw upon aspects of these two orientations to respect to make an argument for the value of framing respect as a practice.

Respect as a Commodity

By respect as a commodity we refer to respect as something that can be given, earned, or exchanged. Early work in this area suggests that one can give respect to another if they assess or appraise the other as having qualities worthy or respect, such as their character traits, abilities, and perseverance (Darwall 1977). This kind of respect, which is also referred to in this earlier work as "appraisal" respect, positions the giver of respect with the power to make the decision about whether respect is worthy to be given.

More recent work focused in urban environments has looked at respect as a commodity that can be exchanged as forms of social capital. Instead of the power to give respect, sociologist Elijah Anderson (1999) examines the power to *earn* respect. Specifically, after chronicling life in high-poverty neighborhoods, he argues that students earn respect through their public image: dress, jewelry, expensive possessions, fighting abilities, and family image:

> In the inner city environment respect on the street may be viewed as a form of social capital that is very valuable, especially when various other forms of capital have been denied or are unavailable. Not only is it protective, it often forms the core of the person's self-esteem, particularly when alternative avenues of self-expression are closed or sensed to be … a people's law based on a peculiar form of social exchange that is perhaps best understood as a perversion of the Golden Rule. (1999, p. 66)

How a commodity is understood or valued depends upon the network of actors present to exchange the commodity. Respect as a commodity does not exist on its own. In this sense, respect as a commodity is situated within relationships, a point we take up in the next section. However, we wanted to call attention in this section to the importance of respect as a resource or tool for gaining access to other forms of capital or even for expressing agency. Elmesky and Tobin (2005) draw out this point in their work where they demonstrate, how, in science classrooms, respect can act as forms of social capital that can be used and exchanged (notably, for science cultural capital):

> Respect … can be conceptualized as a form of symbolic capital or a means by which one's status or the identity others attribute to you can be built, lost, or exchanged for other forms of capital (e.g., social and/or cultural). This symbolic capital can be exchanged for social capital; for example, group membership. … We have gained deep insights into understanding respect as a highly valued form of currency in inner-city classrooms. (p. 814)

Elmesky and Tobin sought to understand how such practices constructed meanings (images, practices, symbols) of respect. They considered how, when students and teachers coauthored curriculum, students were afforded opportunities to build the social capital of respect and how this social capital could then be exchanged for science cultural capital. Further, we thought it of great importance to see how the creation of this capital involved listening to voices, often traditionally marginalized in science. We were intrigued by notions of respect as capital and respect as a tangible good that can be exchanged in beneficial ways in a science classroom.

Respect as commodity challenges us to think about who and what is valued in classroom learning communities and the role of teachers and students co-constructing that value. Respect as commodity also helps us to see how such commodities are tied to social contexts, the resources available there, and the roles individuals play in those contexts. We now turn to respect as relationship to interrogate more directly how and why respect is contextually negotiated.

Respect as Relationship

Respect as relationship offers a lens for thinking about the contextual, relational nature of respect and refocuses the conversation from a *commodity* that is exchanged into one that foregrounds respect as a negotiated *stance* toward another. In other words, while respect as a commodity may be negotiated within relationships, in this section we examine what it means to look at respect *as* a relationship.

Respect as relationship is a dialogic, requiring a deep understanding of the other and a sharing of authority. Respect as relationship also draws our attention to how issues of power are connected to respect: respect "create[s] symmetry, empathy, and connection in all kinds of relationships, even those, such as teacher and student … commonly seen as unequal" (Lawrence-Lightfoot 2000, pp. 9–10). From this stance, respect arises from "efforts to break with routine and imagine other ways of giving and receiving trust, and in so doing creating relationships among equals" (Lawrence-Lightfoot 2000, p. 10). In her book, *Respect*, Lawrence-Lightfoot uses the story of Kay Cottle, a classroom teacher as an exemplar to illustrate the uncertain territory a teacher must navigate in regarding respect as relationship: risk, questioning (of both her authority and the content of the class), and "interweaving ideas" from students. The story of Kay is a story of a teacher enacting respect as relationship. We see a teacher sharing authority, making connections, and questioning. Kay is not "given respect" because she is a teacher and in a position of authority; respect is negotiated.

This greatly pushed us in thinking about respect as being constantly renegotiated by participants and contexts.

For our research we needed a way to conceptualize how individuals enact respect as relationship and how students engage in such a practice. We therefore focused on the concept of respect as "expressive performance" acknowledging others for the value they bring to a situation (Sennett 2003, p. 260). Yet respect as relationship is slippery, for operationalizing how one engages in these expressive performances is amorphous. This is where the work on caring offers useful insight.

What is it about teachers like Kay who are willing to navigate the uncertain waters of respect? We believe the answer lies somewhere in the construct of caring. To better understand the relationship and differences of caring and respect, we turned to the idea that caring is a relationship between the one-caring and the cared-for that is neither contractual nor based on rules, but rather is contextual, involving "a constellation of conditions that is viewed through both eyes of the one-caring and the eyes of the cared-for" (Noddings 2003, p. 13). Further, caring relationships develop by promoting respect and building respect from cultural norms and practices (Valenzuela 1999). Yet the question can be asked as to how these relationships are negotiated amidst power and difference. Engaging in "caring" and "respectful" relationships are often the objects of oppression that youth struggle against:

> Less obvious to caring theorists are the racist and authoritarian undertones that accompany the demand that youth … "care about" school. The overt request overlies a covert demand that students embrace a curriculum that either dismisses or derogates their ethnicity and that they respond caringly to school officials who often hold their culture and community in contempt. Misunderstanding about the meaning of caring thus subtract resources from youth by impeding the development of authentic caring and by obliging students to participate in non-neutral, power evasive position of aesthetic, or superficial, caring. …The definition of authentic caring that evolves in this work thus expands on caring theory to include a pedagogical preoccupation with questions of otherness, difference and power that reside within the assimilation process itself. (1999, p. 25)

Lawrence-Lightfoot's notions of authority and questioning and Valenzuela's introduction of power, otherness, and oppression are extremely helpful when thinking about how respect can reinforce or break down issues of power and authority in the science classroom. Respect as relationship highlights how respect is always an act of positioning and criticality. How one orients himself or herself to care for others while recognizing power dynamics that structure those relationships makes respect possible.

Analytic Lens: Respect as Practice

Based on the scholarship around respect as commodity, as relationship and caring, we put forth a framework to help us think about the dynamics of respect in science classrooms. *Practices of respect* are context-specific actions individuals take to publicly appreciate or develop understandings of others and their value. Thinking about respect in this light operationalizes respect as commodity and respect as relationship. By considering the actions one takes, we can think about how individuals construct respect in the classroom. Further, this lens can help us to understand how and why participants seek to engage in science learning opportunities as well as to think about issues of identity development. We hope to bridge the concepts in the literature of "respect as commodity" and "respect as relationship" into thinking about how (1) practices of respect value traditionally marginalized resources and identities and (2) how practices of respect acknowledge that authority and power dynamics are in constant renegotiation by participants.

Science, although biased and socially constructed, does not have to be a *prejudiced* entity. Yet in the science classroom, and in the scientific community, reality tells us that many perspectives and discursive practices are marginalized (Aikenhead and Jegede 1999). Several theorists advocate the transparency of "Western modern science" (WMS) through postcolonial, critical, feminist, and postmodern theories and further call for multicultural science education that deconstructs what it means to learn and becomes enculturated into WMS (e.g. Carter 2004). Science is not objective or value-free – and it certainly is not objective or value-free in the science classroom.

These critical orientations remind us that science education has the potential to legitimize various forms of knowledge, ways of speaking and relating to the world. Deconstruction of power and authority in the science classroom opens the sciences up for all to reconceptualize, providing participants opportunities to make sense of and value the different perspectives, experiences, and histories each other has to offer. Elizabeth Moje (Moje et al. 2004), among others, refers to this kind of hybrid discourse space as "third space," or a "space of cultural, social, and epistemological change in which the competing knowledges and Discourses of different spaces are brought into 'conversation' to challenge and reshape both academic content literacy practices and the knowledges and Discourses of youths' everyday lives" (Moje et al. 2004, p. 44).

Teachers can create such third spaces that value multiple perspectives and experiences by activity leveraging students' funds of knowledge, sense of place, and ways of knowing (e.g., Calabrese Barton and Tan 2009; Lim and Calabrese-Barton 2006). Yet, it is not just the "presence" of these varied perspectives, experiences, and ways of knowing that make possible such third spaces. It is in how such cultural resources are made *to matter* in the classroom – or in other words, how and why they are legitimized in a science discourse community. One way to think about this process is through practices of respect. In this dialogue, it is important to recognize that this type of pedagogy is not possible without sharing authority, co-constructed learning spaces, caring and legitimizing all perspectives.

Authority, or power to persuade others, exists within all relationships: interpersonal relationships with others, our relationships with text, science, and politics. Authority is often seen as a good teacher characteristic, one that allows classroom management and daily classroom routines to function smoothly. Yet, we know that this imbalance of power can undercut relationships. Sharing of authority calls into question the power given to scientific text and scientific critique as well as questioning who has power in the scientific community and science classrooms (Tan and Calabrese Barton 2007). Respect as practice helps to make teachers more accessible to students, adopt teaching practices that include listening to students, and reconceptualize education as collaborative work. For students, it empowers and motivates (Cook-Sather 2002). For purposes of this chapter, we focus on the constructs of teacher–student shared authority for respect.

We present two classroom vignettes to highlight what we mean by each of these points. We conclude by describing how, together, they offer a framework for practices of respect.

Vignette #1: Rankings

Students in Ms S's seventh grade science classroom were just beginning a unit on forces and motion. Ms S taught at a fairly diverse school, where the students are 43% African-American, 37% Caucasian, 15% Hispanic, and 5% Asian/Pacific Islander; about 67% of students receive free or reduced-fee lunches. Ms S is very well liked by her students and the other teachers, and students often spoke to her in confidence about their problems and issues.

Our first vignette, Rankings, describes an activity in which students ordered animals and objects based on speed. The activity was an introductory activity created through the university partnership. The objectives of the lesson aimed at introducing velocity as connected to distance and time. A lab followed this introduction in which students determined their own velocities doing several different activities (running, skipping, hopping) in which the distance was predetermined and they had to calculate time. Notice throughout the transcript if and how answers are accepted, challenged, or questioned. The transcript begins with one of the students reading the directions for the class in which students are asked to predict the rankings of fastest to slowest animal or object; these animals/objects include 13 items: running turtle, deer, fast walker, attacking hawk, mile a minute, Olympic sprinter, fastball pitch, race horse, lightning bolt, jet plane, fox, car moving at 50 miles-per-hour, running cheetah. Students work on these lists individually and after several minutes, Ms S opens the discussion for students to share their rankings.

1	Ms S	Alright guys. Which one do you guys think was the fastest one? Raise your hand. Yvette?
2	Yvette	The lightning bolt.
3	Ms S	The lightning bolt. Does anybody agree with Yvette with the lightning bolt?
		(*Several students raise their hands, including Fergie*.)
4	Ms S	Alright. Fergie, why do you think the lightning bolt is the fastest one?
5	Fergie	I don't know.
6	Ms S	Who, Why did you put number one next to it? What made you think the lightning bolt had to be faster than the rest of them?
7	Fergie	He told me. He told me. (*points to Joey, who is seated beside her*)
8	Ms S	Cause you listened to Joey. Why would you listen to Joey?
9	Ms S	Alright, Veronica why did you put lightning bolt?
10	Veronica	Because it's fast and it goes real quickly it goes down and then back up (*moves her hand in sync with the words showing it going down and up*)

11	Ms S	So you've seen it before? (*Veronica shrugs her shoulders*)
12	Ms S	Okay. Anybody else? Shawn?
13	Shawn	'Cause lightning travels faster than anything.
14	Ms S	So he's saying light travels faster than anything. How did you know that?
15	Shawn	'Cause I listened in science class last year.
16	Ms S	Alright. Thomas?
17	Thomas	'Cause it's just energy.
18	Ms S	'Cause it's energy. Kay. What about this energy? Explain Thomas.
19	Thomas	I don't know.
20	Ms S	You just think 'energy' when you think of lightning bolts and that just seems fast to you.
21	Yvette	I've seen it. It'd just be like (slices her right hand horizontally across the air and purses her lips as though about to make a "whoosh" sound)
22	Ms S	Say it again Yvette. Why did you think lightning bolt was fastest?
23	Yvette	'Cause I've seen it!
24	Ms S	You've seen it. You've seen lightning bolts before. (*later in the discussion*)
25	D'Angelo	We always compare everything to lightning. When we talk about speed they always say "moves as fast as lightning".
26	Ms S	Yeah! You guys have all heard that saying before. D'Angelo's right. You always hear, "So-and-so's fast as lightning" or "This thing is as fast as lightning." So he's taking that little quote and saying, "Well then, lightning must be pretty fast then if everything's being compared to it." Okay? That's good.
27	Ms S	Yeah, Evan?
28	Evan	Because everything else on the list has to start off slow then go fast, but lightning doesn't.
29	Ms S	Okay. So he's saying that everything else on here kinda starts off slow and then has to build up speed to become fast, right? While lightning is just kind of quick all the time.
30	Thomas	No.
31	Ms S	That's what he's saying. It's okay. Do you think something different Thomas?
32	Thomas	Yeah, it's fast, the fastest one on the list but as it hits something it slows down.
33	Ms S	Okay. As it hits something it slows down. (*Ms S later gives the students the 'correct' rankings.*)

This transcript helps us to both unpack and also make problematic what it means to engage in practices of respect in a seventh grade science classroom.

On the one hand, Ms S designed an activity and conducted a classroom conversation meant to help students elicit their own experiences and stories to open up a conversation on velocity: moving from student to student, allowing all answers into the discussion, using popular culture and personal observation as evidence. Further, each student was given the opportunity to share his or her ideas – this can be interpreted as actions demonstrating appreciation for others. In this transcript we see many students engaging in the activity. These actions, on the part of Ms S, provided entry points into the science for students – allowing them the floor to try out new ideas and possibly new scientific identities. It is important to note, for example, that some students spoke in this episode with ideas and with excitement who rarely spoke in other class periods. While many teachers jump at the "correct" answer or the answer that neatly aligns with their ideas, Ms S allowed the conversation to move in the directions dictated by student ideas. Though we see Ms S's enthusiasm for some ideas over others (as evidenced by questioning and her exclamatory remarks), she still invites in all student ideas. Through accepting and valuing responses all students' responses, she provides the space for students to participate.

On the other hand, Ms S appears to be valuing all students' responses regardless of their scientific validity or their connection to students' own experiences. Two different dynamics seems to be going on in this class session. First, students appear to draw upon each others' ideas to raise their own and to ask questions, which aligns with Ms S's goal to elicit more student participation and interest. In the discussion of "what is fastest," we see students using each other's ideas in the space created for this discussion. We also see how students are using evidence to support their thinking and what is valued as evidence. For D'Angelo, lightning is fastest because of an expression. For Veronica and Yvette, lightning is fastest because they have seen it (and use dramatic action to share the experience). For Shawn, he relies on content from last year's science class. For Fergie, she is listening to another student, Joey. For Thomas, it is because it is energy. For each of these different responses, each is given the floor by Ms S and their ideas are invited into the discussion. While some are traditionally valued evidence in science classrooms like Shawn's, we also see the use and validation of nontraditional evidence by the students and teacher as well. Second, Ms S seems to privilege student participation as "doing the work" of school rather than trying to develop deeper understandings of others' ideas or of the science involved. We explain these points below and use our respect as practice framework to challenge our understanding of this episode.

But a closer look at the transcript reveals that while Ms S is valuing her students' responses publically and legitimizing their wide range of resources, including how the students co-gesture the speed of lightening, she may be working toward respecting their identities as good students and worthwhile people rather than also supporting them in engaging deeply in science. Look what happens when one student, Thomas, tries to challenge another student's claim (line #30). What is particularly interesting in this is twofold: (1) Ms S stands up for Evan, telling Thomas "That's what he's saying, it's okay" and then asking him for his opinion. Again, we see that all student ideas and opinions are given equal value – all are accepted as valid. (2) Thomas disagrees with this notion that lightning is, as Ms S states, quick all the time. His disagreement, that lightning is quick all the time, is not necessarily disagreeing with his peer, Evan, but the way Ms S paraphrased it. While this statement is not discussed as a large group, Ms S does validate and accept it: "Okay, as it hits something it slows down." Throughout this discussion, students state an idea and all ideas are accepted, regardless of student challenge. Ms S has privileged contributing ideas over asking questions. Further, in doing so she potentially privileges the wide range of resources that her students bring to learning about velocity. We use the phrase potentially because while the discourse in the classroom is one where Ms S uses her authority to create the space to allow these resources to become public tools for all to use, she also truncates the space because she does not further support students in taking up these tools to reason more critically about velocity.

If practices of respect move toward also supporting student learning, then teachers and students need to have the space to try on new identities in the classroom that might be at odds with traditional identities for the classroom. Here, Thomas seems to be trying to engage the science. In this sense he is asking to be respected for his science thinking. In this vignette, as Ms S pushes against Thomas's questioning (not valuing Thomas' effort to try out scientific reasoning) in defending Evan's idea (valuing the story that Evan brings to the classroom), she also cuts off opportunity for dialogue among the students – in a sense keeping identity development in check. As such, practices of respect in the classroom seem to reflect what it means to be a good student and even possibly a worthwhile person (that is, one with good ideas), without really considering science learning. A student like Thomas would need the space to challenge a claim (not necessarily fitting a "good student" identity in this class, but allowing for learning). The question then becomes, how are practices of respect negotiated in these classes where such space is created?

Science education has the potential to legitimize various forms of knowledge, ways of speaking and relating to the world. This is where practices of respect enter. As both teacher and student conceptualize what "counts" in science, we believe many marginalized voices may be heard. If we open up how students might initially "talk" in science, then this values the individual as an important contributor and coproducer of scientific thinking, rather than a student who has only the ability to share the right or wrong answer. It is important to recognize that this type of pedagogy is not possible without sharing authority, co-constructed learning spaces, caring, and legitimizing all perspectives. Both teacher and student must enter this dialogue practicing respect.

As we see here, entering into a science discussion in a nontraditional way does not necessarily mean that the student will learn science or gain more meaningful access to science trajectories or science talk. Thus we see the complexities within practices of respect tangled up in social structures, expectations, and positions of power. This vignette also challenges us as we think about authority and sharing power. On one hand, we can see the invitation of student ideas and a conversation that breaks away from more traditional forms of science discussion. Yet we are also reminded that the teacher ultimately holds the power and reminds students verbally as she shuts down Thomas' questioning.

Vignette #2: Rules

In the second vignette, we are allowed access to some of the community's values in terms of its discursive norms and activity. The previous day, the students engaged in their favorite lab of the unit in which they hopped, skipped, jumped, ran, and walked to determine various velocities. The day of the "rules" vignette, they were talking about the reference points and velocity students experienced, witnessed, and calculated the day before. About 20 min into the class period, the teacher stops the discussion and tells students to take out books and start working from the textbooks. In this classroom, bookwork was seen as a punishment. The teacher then tells the students

> I just don't think you guys in sixth hour are getting the message at all. I called parents twice, sent people out to the office, given you detentions. What is it I can do to help you? I'm serious. Raise your hand. There's something I can do, something that would work better.

A student raises his hand and is called on. "Everyday, split the class up with the kids who talk and the kids who don't talk on one side, the kids who do talk on the other … and with the kids who talk on one side, just give them homework. 'Cause then you could tell who's talking." The teacher replies that she wishes she could and that she has considered it. Another student later recommends a similar idea "…You give the kids that aren't doing what they supposed to bookwork and all the other kids do like the experiments and work on computers and stuff instead of punishing everybody." The teacher then asks the entire class to stop what they are doing and write down two rules they would like implemented,

> What do you think the two most important rules should be in this class? Here's a couple questions to think about. What would make you guys more successful in this class? Are there some rules that would help that? What would make you feel more safe, or more comfortable, in this class? Are there some rules that would help that? We said this before, science is supposed to be fun, hands-on, talk to everybody as a group, talk about your evidence, your experiences, your reasonings. The things that go around on the world around you. Are there rules that could help that happen?

As students are writing, Ms S comments: "Obviously there's some disconnect between you and I, or you guys and each other, the class and Ms. P. I don't know. There's some sort of disconnect and we need to figure it out. This isn't a punishment right now. We're just trying to figure out how things should run in here." Students suggest and discuss the following ideas: (1) don't talk when teacher's talking during lesson, (2) less work, (3) raise your hand to talk, (4) everyone should pay attention to the teacher, and (5) do our work.

In the end, the teacher summarizes the class rules:

> It really all comes down to, or at least what you guys are showing me and telling me from all of these rules and suggestions, it's really coming down to one word "respect." Okay? Respecting yourself, respecting me, respecting Ms. P., respecting your other classmates. We know sometimes you guys have your days and you're not gonna be perfect everyday. But today, would most of you guys agree that you were being pretty ridiculous?
>
> (*No student seems to respond.*)

> Off-task, talking, not paying attention, not respecting your classmates, not respecting me, not respecting yourself, because that's what you're here to do is to get an education. You're not respecting yourself when you're not trying to do that.
>
> (*She later repeats this summary*.)
>
> Alright, so overall you guys would agree that we need to respect each other. That's our big number one rule, right? There are some sub-rules we can add to that like "Make sure you're listening when somebody else is talking," right? Alright, does anybody disagree with Thomas and, like, Sean's suggestions about splitting the kids up?
>
> (*Students were separated by teachers at a later date, utilizing two of the student's suggestions*.)

In this vignette we see what discourses and activities are privileged in this science classroom. First, according to Ms S, science is "fun, hands-on, talk to everybody as a group, talk about your evidence, your experiences, your reasonings" and, as such, bookwork (reading and answering questions from the book), are seen as punishment and not "good science." Students take up and reinforce this idea by suggesting that students who are not behaving appropriately should be given bookwork, but students who are behaving appropriately should be able to do experiments and work on the computers. There seems to be an underlying idea that, according to students, all students should have access to science, even if being punished with bookwork (vs. being asked to leave the classroom). Second, we see how the teacher connects classroom management and rules to access to science. For her, the teachers and students must remedy this "disconnect" in order to engage in science. This is so important, in fact, that she asks the class to stop the bookwork and punishment and write two rules. As a beginning teacher, we can understand the difficulties and frustrations of "managing" a classroom. As punishment for not doing "school" right, Ms S removes access to science. Third, we begin to understand, how the teachers view respect: through courtesy (raising hands, listening to teacher, students doing work); and respecting oneself and others is how one gets an education. One can also see the teacher making an attempt to reach out and listen to student input.

Looking back to our framework, one could consider this an action the teacher is taking to publicly appreciate or develop understandings of others and their value, through trying to share authority, negotiating spaces (rules), legitimizing comments of students, and by trying to remedy the perceived disconnect between teachers and students. The students coauthored this practice by offering their own rules for how to remedy the disconnect and explaining to their teacher that they valued all students having access to science, even if the "talkers" only had access to "bad science" (i.e., book work).

The difficulty in looking at this scene may illustrate several instances of practices of respect that emerge when one considers issues power and privilege. For example, how is it problematic for a teacher to accept and enact a student-suggested rule that recommends splitting and labeling the students in a classroom? Similar to the Rankings vignette, we see the teacher still is safely positioned with the power and authority despite outward attempts to share this power. In one light, one can see a teacher taking up a student suggestion, on the other hand, one can see the implementation of this rule as troubling. Another way to trouble this scene is by thinking about nature of the conversation as procedural and management-based.

This vignette leaves us with several questions as we consider the contradictions and intricacies embedded within practices of respect. Could this conversation move to one about how students relate to material, connect the science in their lives to classroom science, or to think about deconstructing science? If we know that students are thinking about science in complicated ways, how can teachers elicit these conversations? Thinking of Valenzuela's discussion of caring as one that "include[s] a pedagogical preoccupation with questions of otherness, difference and power that reside within the assimilation process itself," we wonder how this conversation could really push on the ideas and boundaries of practices of respect. In what ways was the teacher engaging in a practice of respect and in what ways was she not? In what ways do practices of respect influence student engagement in a science classroom?

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Neither science education nor our students exist within a vacuum. In very complicated and nuanced ways, teachers and students must deeply understand the dynamic nature of context in order to engage in respect. Learning is situated; it is "a process in which outcomes and goals are shaped by learners as well as by other historical, political, social, cultural, and physical factors" (Calabrese Barton and Brickhouse 2006, p. 223). Building on this idea, the authors describe the embodied nature of science and help us to think about how learning science goes beyond learning content and facts but involves learning how to participate in scientific communities and discussions. This learning has to be contextual: it is necessarily historical, political, and cultural and because of its humanity, requires us to think about the people (students) involved in the science classroom. Here we see that both science context and identity development are dynamic. The recognition of science as contextual and dynamic allows for practices of respect to be co-constructed.

Practices of respect call into question the idea that science teaching and learning is a neutral process. What and how students learn is deeply situated within a sociocultural and historical context and embracing such contexts makes possible a teacher's or student's ability to engage the other in thoughtful ways. "Unpacking" or "making sense of" the contexts (and the power dynamics therein) that shape context is an important part of the process of understanding others. If, for example, the way we teach science in schools leaves silent the sociocultural features that surround the "making of a scientific fact," then how students learn to value each other as users and producers of science is also made silent. Respect is important for how students and teachers engage in the class in that it increases both teacher and student engagement. Further, practices of respect help us question *who* is allowed to learn and *what* students are allowed to learn.

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Chapter 36
Science Education in Rural Settings: Exploring the 'State of Play' Internationally

Debra Panizzon

The existence of the *Journal of Research in Rural Education, Education in Rural Australia, Rural Educator* and the *Rural Society Journal* reflects that rural education is a clearly defined area of research. Reviewing the articles represented in these publications highlights (a) a broad diversity of topics pertinent to the research area (see Arnold et al. 2005 for a recent synthesis) and (b) an apparent dichotomy around the focus of the research. For example, at one end of the spectrum, studies emphasise what Mary Jean Herzog and Robert Pittman (1995) refer to as a 'deficit model' of rural community and lifestyle as they explore the issues and challenges experienced by schools situated in these locations. Debra Holloway (2002) provides an extensive synthesis of this literature as she discusses the variety of concerns facing teachers working in rural communities in the USA. At the other extreme, research accentuates the high rate of success underpinning education and schooling in rural areas (Haller et al. 1993; Alspaugh and Harting 1995; Arnold 2001; D'Amico and Nelson 2000). Joyce Stern (1994) particularly acknowledges the early 'pioneering' role of rural teachers in the USA by implementing strategies around multi-grade teaching, cooperative learning, interdisciplinary studies, peer tutoring and block scheduling, which are now commonplace in classrooms across the globe.

This dichotomy is also evident in the science education literature, although the pool of available studies with a focus on rural settings is considerably fewer. The most recent publication by James Steve Oliver (2007) is a book chapter entitled *Rural Science Education* in which he addresses four broad aspects. First, he considers the many difficulties around defining 'rurality' and attempts to identify characteristics of rural schooling that are 'universal'. Second, he provides a historical perspective on research in science education from the 1960s to the 1990s that

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describes the condition of rural science teaching during the period. While focused predominantly on research conducted in the USA, the findings are pertinent to other countries facing similar challenges. Third, he outlines the Rural Systemic Initiative Movement in Science, Mathematics and Technology Education (RSI) in the USA and six drivers to use as "guideposts or standards about which the progress of systemic reform could be measured" (2008, p. 357). Finally, he discusses the ramifications and implications of these findings for teacher education programs. This is a critical component if educational authorities are to devise policy around the provision of challenging, relevant and opportune pre-service and in-service professional development to address the needs of rural science teachers.

The work of James Steve Oliver (2007) and others begins to unravel the apparent inconsistencies in the research data for rural settings. This chapter attempts to develop the area further by exploring the following questions. What is the extent of the impact of a rural location on student achievement in science internationally? What can we extrapolate from the existing research around rural education that helps to explain the dichotomy in the findings? Considering the research findings more holistically, what direction for science education in rural settings emerges for the future? Subsequently, rather than critique a range of individual research studies around science education in rural settings (given that this already exists), this chapter identifies the major themes emerging from this prior research and attempts to provide a broader and holistic perspective upon which to consider future directions.

Student Achievement in Rural Settings

In considering the research available around science education in rural locations, student achievement is often a prime area of focus. This is one area where inconsistencies in the data proliferate, with some studies suggesting that students in rural areas achieve more highly than their peers in urban centres (Fan and Chen 1999) while other research suggests that the reverse is the case (Canadian Council on Learning [CCL] 2006; Panizzon 2009). What is most interesting from a research perspective is when these discrepancies occur *within* the same country. For example, in the case of the USA, Frank Beck and Grant Shoffstall (2005) found that rural students in Illinois attained higher results for the Illinois Standards Achievement Test (ISAT) than their urban peers. Alternatively, Vincent Roscigno and Martha Crowley (2001) identified that students in rural areas exhibited lower levels of achievement than urban students using National Longitudinal Education Study (NELS) data. Clearly, one issue emerging here is that comparisons within or across countries are difficult given the lack of a common metric or standard upon which to base the evidence. This is complicated further by the alternative definitions of rurality used in particular studies (Kannapel and Young 1999 for the USA; Lyons et al. 2006 for Australia). However, data from the Programme for International Student Assessment addresses both issues and provides a common metric and consistency around a definition of ‘rurality’. For PISA, geographical locations are defined solely around population size:

1. Village, hamlet or rural area with fewer than 3,000 people
2. Small town with between 3,000 and 15,000 people
3. Town with between 15,000 and 100,000 people
4. City with between 100,000 and 1,000,000 people
5. Close to centre of a city with over 1,000,000 people (OECD 2006)

To facilitate a comparison across participating countries, mean scores for science from PISA 2006 were reviewed along with their standard errors (*SE*). This measure expresses variation around the mean, with a lack of overlap of *SE*s suggesting significant differences between the individual values. Results of this analysis for selected countries are summarised in Table 36.1.

In reference to Table 36.1, three broad patterns in relation to location are identifiable including countries in which the:

- Mean score for rural students is considerably lower than urban students’ scores
- Mean score for urban students is lowest when compared to all other locations
- Mean score variation across geographical locations is minimal, suggesting a high degree of homogeneity

Considering the first set of countries, the relatively low *SE*s across PISA categories for Australia, Canada and to a lesser extent New Zealand is indicative of potential significant differences. The extent of the ‘rural versus urban’ divide in student achievement for these countries is supported by research including Lyons et al. (2006) for Australia, the Canadian Council on Learning (2006) for Canada, with Panizzon (2009) reporting initial evidence of a gap in New Zealand. The data for Korea suggest a clear gap between the rural students (i.e. PISA categories 1–2) and students in more urbanised areas (i.e. PISA categories 4–5), even though the *SE*s are high for a number of these categories. Germany is interesting in that students in small towns and cities (i.e. PISA categories 2–4) achieved more highly than both highly rural and urban students (i.e. PISA categories 1 and 5, respectively). However, the high *SE*s for three of these categories indicate that the differences might not be significant, thereby explaining why this gap is not documented in the literature.

In contrast to this first group of countries, results for the UK and the USA suggest that rural students achieve higher mean scores than their urban peers. While little research is available to corroborate the results for the UK, as discussed earlier, there is considerable research data from the USA that provides conflicting results about student achievement according to geographical location. It is interesting to note that, in the USA, the highest mean score is for PISA category 3 representing centres with populations of 15,000–100,000 people. Clearly this raises the issue about how ‘rural’ is defined, which goes part of the way in explaining some the inconsistencies in the data for the USA. This aspect is discussed in detail later in the chapter.

The final pattern of countries including Denmark and Ireland suggests a high degree of homogeneity with minimal differences in the achievement of students in

Table 36.1 Patterns of science means for PISA 2006 based on geographical locations

Pattern across geographical location	Examples of countries	PISA category	*M*	SE
Rural mean score lowest across locations	Australia	1	502	8.01
		2	507	6.22
		3	518	4.22
		4	536	4.38
		5	536	4.57
	Canada	1	507	5.68
		2	539	4.21
		3	537	3.34
		4	539	4.01
		5	535	7.51
	Germany[a]	1	453	14.94
		2	516	7.73
		3	526	7.70
		4	521	13.61
		5	487	17.77
	Korea	1	469	16.18
		2	463	14.16
		3	505	10.90
		4	528	4.91
		5	527	5.68
	New Zealand	1	499	9.52
		2	518	11.08
		3	530	5.67
		4	545	4.93
		5	530	6.75
Urban mean score lowest across locations	UK	1	549	11.88
		2	528	5.69
		3	518	5.01
		4	503	7.72
		5	501	15.20
	USA	1	497	5.73
		2	485	6.67
		3	511	6.57
		4	486	12.72
		5	440	12.88
Minimal difference in mean scores across locations	Denmark	1	489	5.97
		2	495	5.45
		3	498	4.44
		4	496	11.27
		5	532	16.43
	Ireland	1	501	5.43
		2	512	4.90
		3	502	6.99
		4	513	13.23
		5	516	8.36

[a] Different pattern from other countries in the group

relation to location evident from the data. Hence, neither country is likely to be represented in the rural education literature, which does appear to be the case.

Subsequently, this broad analysis of data patterns indicates that the gap between the achievement of rural and urban students appears to be an international issue for a number of countries that participated in PISA 2006. However, other examples are evident in the literature with Adebowale Akande (1990) highlighting a gap for Nigerian students; Christine Liddell (1994) within the South African context; Harold Stevenson and colleagues (1990) for Peruvian students; and, finally, UNESCO (2003) for students in South American countries. Critically, only a small proportion of these countries is represented in the research literature.

In an attempt to explain this particular outcome, it is important to recognise the need for higher-level statistical analyses to ensure that confounding variables do not mask the impact of location. An excellent study that demonstrates the importance of statistical procedures being applied and implemented in this manner is provided by James Williams (2005) in a detailed study of PISA 2000 mathematics results. A number of the aspects raised by Williams are discussed in the following section.

Reflecting on Rural Science Education Findings

An audit of the science education research literature for rural settings highlights a wide diversity of topics impacting rural schools including teacher recruitment and retention (Holloway 2002), teacher subject knowledge (Carlsen and Monk 1992), teacher qualifications (CCL 2006), teacher preparation and the quality of ongoing professional development (Holloway 2001; Oliver 2007), accessibility to resources (Truscott and Truscott 2005) and teacher expectations of students (Gilbert and Yerrick 2001). Again, there are often contradictions about the extent to which these aspects impact on rural schools. To help explain some of these discrepancies, Wang Fan and Jin-Quan Chen (1999) highlight four potential limitations in relation to the research findings including: (a) inconsistent and unclear definitions of rurality; (b) the potential for ethnicity and the school sector to act as controlling variables; (c) issues around school selection and the research sample; and (d) socio-economic status (SES) as a confounding variable.

Potential Limitations of Previous Studies

1. *Definitions of rurality*. Implementation of different criteria across and within country comparisons make comparative studies meaningless because population size (OECD 2006; Stern 1994), school size (CCL 2006; Huang and Howley 1993; Simpson and Marek 1988) or the area served by a school (Liu and Brinlee 1983) are used to categorise rural and urban localities. Complicating this further, students live in what can be defined as urban locations but they choose to travel

to rural schools. This increased mobility makes it even more difficult to define 'rurality' (Gilbert and Yerrick 2001).

2. *Ethnicity and the school sector as controlling variables*. Fan and Chen (1999) suggest that ethnicity varies markedly across geographical locations, although, historically, there was greater homogeneity in rural areas (Nachtigal 1982). Given that links between ethnicity, poverty and socio-economic status are identifiable in the broader research literature, researchers suggest that ethnicity needs to be considered as a confounding variable in any analysis of rural settings (Biddle and Berliner 2002; Truscott and Truscott 2005). Similarly, few studies differentiate between public and private school sectors in their designs, even though significant differences in student achievement between the school sectors are evident in the research data (Fan and Chen 1999). This aspect is elaborated upon in relation to the research sample.
3. *School selection and research sample*. James Williams (2005) and James Oliver (2007) raise the issue of relying on convenience or local samples of schools that do not provide appropriate representation. In their view, most rural research merely incorporates rural schools because of convenience, with few research studies actually seeking to understand the 'rural-specific issues' relevant to the context. As quoted by Mary Jean Herzog in Topper Sherwood (2000, p. 161): 'People will do a study in a rural area and think this makes it a rural study; but they aren't necessarily the same thing'. This aspect was explored by Michael Arnold et al. (2005) through a detailed audit in which they filed studies into two possible categories. *Rural-specific studies* focused on issues in rural schools and were indicative of 66% of papers. In contrast, *rural-context studies* explored generic issues in rural school and accounted for 34% of the literature. Such representation is positive although Fan and Chen (1999) suggest that, without a non-rural setting for comparison in any rural study, it is impossible to discern generic teaching-related issues from those that are rural-specific. Importantly, comparative studies across urban and rural settings are rare in the science education literature.
4. *Socio-economic status (SES) as a confounding variable*. There is already a strong correlation demonstrated between student achievement and socio-economic status in the literature (CCL 2006; Howley 2003; Khattri et al. 1997; Williams 2005). In many countries (e.g. Australia) rural settings tend to have lower socio-economic status than urban areas so that any analysis that does not control for this variable hides the actual impact of locality on student achievement in science (Lyons et al. 2006). For example, in a large-scale study of rural Australian students in science, Diedre Young (1998) used multi-level modelling techniques to control for SES to highlight that students were not disadvantaged by location but by differences in relation to their self-concept. In her view, student variability in science achievement was influenced more at the level of student and classroom than by geographical location. To explain this result further, Williams (2002) suggests that, while Young (1998) considered community-level SES, it is critical to distinguish this from school-level SES, which is overlooked in the majority of research studies.

Attempting to Address These Research Limitations

A number of these limitations were addressed in a large-scale national study conducted in Australia around science, mathematics and information and communication technology (ICT) education (Lyons et al. 2006). The study consisted of five questionnaire surveys designed for primary teachers, secondary science, ICT and mathematics teachers and parents. Essentially, the science teacher surveys sought views around the availability of: (a) qualified science teachers in schools; (b) material resources and support needs; (c) accessibility of professional development; and (d) the availability of science learning experiences for students.

Schools in the study were categorised using the MCEETYA Schools Geographic Location Classification based upon population size and accessibility to a range of facilities and services to produce four main categories: Metropolitan Areas, Provincial Cities, Provincial Areas and Remote Areas (Jones 2004). Surveys for secondary science teacher were distributed to 1998 secondary departments or faculties (i.e. high schools) in all provincial area and remote area schools (i.e. rural schools) across Australia, along with a stratified random sample of 20% ($n = 291$) of metropolitan secondary departments. Responses were received from 580 secondary science teachers representing 334 secondary departments.

A number of analytical strategies were implemented including chi-squared tests on categorical data, principal components analysis on Likert Scale items, and MANCOVAs for comparing the component scores across various respondent categories (e.g. sex, indigenous populations). The MANCOVAs also controlled for the effects of school size and the socio-economic background of the school location. Some of the major findings were:

- Science teachers in different locations reported significant differences ($p < 0.001$) in the annual turnover rates of staff and the difficulty in filling vacant science teaching positions when compared with teachers in metropolitan schools.
- Science teachers in provincial cities and areas were twice as likely, while those in remote areas were four times as likely, as those in metropolitan areas to identify that it is ‘very difficult’ to fill vacant science teaching positions in their schools.
- Science teachers in provincial areas were twice as likely, and those in remote areas were about three times as likely, as those in metropolitan areas to teach a science subject for which they are not qualified.
- Science teachers in provincial and remote areas demonstrated a significantly ($p < 0.001$) higher unmet need than teachers in metropolitan areas for professional development opportunities that provide help with teaching targeted groups of students (e.g. gifted and talented, indigenous and special needs). In contrast, teachers in metropolitan schools had a lower level of unmet need for *every* professional development and resource item (e.g. laboratory consumables) included in the survey.

Incorporation of a representative sample of rural and non-rural schools in this study facilitated the comparisons necessary to identify significant differences between the needs and experiences of secondary science teachers across geographical locations in Australia. Strengthening the emergent findings from this study was the controlling of school size and socio-economic status, thereby addressing some of the limitations identified in previous research (Arnold et al. 2005; Fan and Chen 1999; Williams 2005). Another positive outcome of the study is that it provided an opportunity to compare the findings across secondary science, mathematics and ICT teachers given that similar but separate surveys were implemented with each group of teachers (see Lyons et al. 2006 for the full report).

However, one of the constraints of the national study was the focus around issues already evident in the literature (i.e. retention, resources, professional development). So, while it provides substantive evidence for Australian educational authorities about prevailing concerns around the teaching of science in rural settings when compared to other geographical locations, it did not allow other factors not yet identified in the literature to be investigated.

Clearly, much is known about the types of factors that influence the effectiveness of science teachers in rural communities, even though the data are somewhat inconsistent. The discussion of potential limitations of previous research goes some way in explaining some of these ambiguities but not all. Another key component to recognise is the diversity that exists among schools and communities that are designated as rural. For example, Mike Arnold (cited in Sherwood 2000, p. 161) suggests that 'there is poor "rural" and wealthy "rural". There's "rural" with no minorities, and "rural" with high minorities'. Similarly, Jerry Horn (1995, p. 3) states: '[T]he simple fact is that rural people, rural communities and rural conditions are so diverse that one can find evidence to support nearly any characterization'. Hence, it is recognition of this variation within rural settings that helps to explain further the discrepancies in the data around student achievement and the impact of schools in not only rural but also urban education. This component is explored in more detail in the final section of the chapter.

Future Directions for Rural Science Education Research

In 'stepping back' from the literature, alterative perspectives emerge that compel us to consider science education in rural settings in a more holistic fashion. Before exploring this avenue further, it is imperative to recognise what Alfred Schultz referred to as a 'life-world' (Schultz and Luckmann 1973) around rural communities that must be understood to appreciate the complex and highly dependent interactions that exist between rural schools and the communities in which they reside (Barley and Beesley 2007; Harmon et al. 2003; Howley et al. 2005). Critically, this life world is very different from that of an urban setting, which explains the importance of specific science education research for rural and urban settings. However, given this premise, it is possible to identify similarities across the two spheres that 'unifies the cause' (Truscott and Truscott 2005). For example, Howley et al. (2005, p. 3) suggest that:

> [r]ural education research simply must ask what sort of schooling rural kids are getting, why they are getting it, who benefits, who gets injured in the process, and by what mechanisms?

Surely, the same questions are pertinent to research around urban schooling? Perhaps finding an alternative way of conceiving the research area will help to overcome some of the difficulties experienced by researchers in their attempt to develop a coherent research framework around rural science education (Kannapel and DeYoung 1999; Lyons et al. 2006; Oliver 2007). As expressed by Topper Sherwood for the US context (2000, p. 164):

> Researchers have tried to establish a 'rural education research agenda' at least since 1984, but no effort seems to have been dynamic enough – or well funded enough to capture the research community as a whole. Successes in rural research have been as isolated as some rural communities.

Diane Truscott and Stephen Truscott (2005) provide a radical exemplification of an alternative lens by suggesting the replacement of the rural–urban antagonism with a 'high-need versus resource-rich school' perspective (p. 1). In their view there are four critical factors that impact on the quality of education received by students regardless of location.

1. *Catering for increasing diversity*. Truscott and Truscott note that, over the last decade, there has been an increase in ethnic and racial diversity in many rural communities in the USA as people migrate away from urban centres in search of work. Subsequently, there is no longer the ethnic homogeneity assumed in much of the early rural education literature (Nachtigal 1982).
2. *Overcoming childhood poverty*. One of the most ubiquitous challenges for all schools is that poverty is linked not only to ethnicity but also to lower student achievement and self-efficacy (Biddle and Berliner 2002; Teachman et al. 1997; Young 1998). Quite simply, 'poor children fare worse in school and are less likely to graduate from high school' (Truscott and Truscott 2005, p. 2). This statement is supported by research evidence that recognises poverty as an issue in both rural and urban schools, with traditional generalisations about the wealth of rural communities in the USA being no longer applicable (Michael Arnold cited in Sherwood 2000; Horn 1995).
3. *Lack of adequate financial resources*. Biddle and Berliner (2002) suggest that having inadequate resources aligns strongly with poverty because schools with a higher proportion of poor students often receive less government funding. While urban or metropolitan areas are known for poverty and a lack of adequate resourcing (Calabrese Barton 2007), Truscott and Truscott (2005) allude to the high levels of poverty in many rural communities in the USA where science teachers constantly struggle to obtain the funds needed to maintain school laboratories. Similar findings around resources emerged for research involving Australian secondary science teachers (Lyons et al. 2006).
4. *Recruiting and retraining 'good' quality teachers*. While often alluded to in relation to rural settings (Barrow and Burchett 2000; Holloway 2002), many urban schools also struggle to recruit and retain qualified science teachers (Calabrese Barton 2007).

Collectively, these factors encompass the notion of *equity* and the recognition that some schools, because of their clientele, geographical location, SES or community context, require more support if they are to provide their students with educational opportunities equivalent to those in the 'resource-rich schools' referred to by Truscott and Truscott (2005). Exploring this area further, Angela Calabrese Barton (2007) discusses an *equity metric* for science and mathematics developed by Jane Butler Kahle (1998) for implementation in urban schools. The resource-based indicators (e.g. course enrolment, quality of courses, teacher expectation, instructional quality, out-of-school experiences) used to assess the degree of equity in urban schools are equally appropriate for rural schools.

Similarly, Steve Oliver (2007) identifies six drivers guiding systemic reform in rural education in the USA that are relevant to schools in urban areas: (a) a standards-based curriculum; (b) consistent policies to ensure high-quality science education; (c) convergence of resources; (d) unification of stakeholders towards a common goal; (e) the need for quality evidence around student achievement; and (f) the basic need to improve the achievement of all students. Subsequently, these examples demonstrate that there is an opportunity to develop a coherent and high-quality research framework across high-need rural and urban schools that incorporates the broader contextual and community factors that impact on schools. The advantage of such a perspective is that it might attract the sustained interest of educational authorities and governments given the focus on a wider cross section of the student cohort. The central thesis presented here is captured succinctly in the following quote from Truscott and Truscott (2005, p. 5):

> The problems facing high-need urban and rural schools are long-standing, deep, and pervasive. The similarities that exist between urban and rural schools are pronounced, as both respond to day-to-day challenges brought on by the effects of poverty, insufficient school funding, and external socio-political demands. Short term fixes and abrupt changes in emphasis cannot succeed. Successfully addressing these problems will require sustained, multifaceted efforts that address many areas simultaneously and evolve continuously.

Conclusion

Evidence from PISA 2006 suggests that there are a number of countries experiencing issues around science education in rural settings. Care does need to be taken in using data sets of this type because of the complex interaction that confounding variables, such as socio-economic status, ethnicity and school size, play in masking differences in student achievement across geographical locations. Interestingly, the investigation of the rural–urban gap in student achievement has been a major focus for the USA, Canada and Australia, judging by its representation in the literature. While rural education research appears to have a well-grounded tradition, this is not the case for science education in rural settings, with studies appearing relatively scant, difficult to access, and often reporting contradictory findings. A major weakness in the research design of many of these studies is the lack of inclusion of both rural and urban schools, which is necessary for meaningful comparisons (Fan and Chen 1999; Williams 2005).

In conceptualising a future research agenda for science education in this area, alternative views are emerging in the literature. The predominant view is about 'stepping back' from the fine detail to focus on the factors shared across geographical locations that restrict and limit the educational opportunities of all students. In other words, we need to raise the issue of *equity* because the research already demonstrates that the main school variables affecting student achievement and learning in science generally include the quality of school facilities, availability of resources and equipment, teacher qualifications and experience, ongoing professional development, and availability of specialists for support and mentorship (Truscott and Truscott 2005). However, improving these factors requires considerable financial resources in densely populated urban areas as it does in sparsely populated rural areas. Framing a research agenda across geographical boundaries has a greater likelihood of attracting the attention of governments and educational authorities because of the broader socio-political implications.

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Chapter 37
Out of Place: Indigenous Knowledge in the Science Curriculum

Elizabeth McKinley and Georgina Stewart

In this chapter we have been asked to address indigenous science education research. This is a topic that has, in the past, been subsumed under wider concepts, such as multiculturalism, equity, and the like. For example, in the first edition of this Handbook, Bill Cobern and Glen Aikenhead's (1998) chapter was the only one with 'culture' in the title. This chapter promoted the view of science teacher as culture broker, which suggested that teachers need to facilitate cultural border crossings for their students from their own cultural backgrounds to that of science education (Aikenhead 1996; Michie 2004). However, four other chapters were equally relevant to the interests of indigenous students and communities – Dale Baker's (1998) on equity, Douglas Allchin's (1998) on values, Michael Matthew's (1998) on the nature of science, and Arthur Stinner and Harvey William's (1998) on the history and philosophy of science. Indigenous science education and research occurs at a nexus of complex philosophical, historical, psychological, sociological and political relationships that tend to overwhelm the focus on achievement. Unfortunately, these understandings are not held by most science teachers, education officials, or education academics. It is on the latter group, as Graham Smith (1995) argues, that the primary responsibility lands for initiating the work towards ameliorating this lack, despite its limitations. In this chapter we argue that failure to fully understand these complexities is a limiting factor overall in indigenous science education research to date.

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The title invokes two meanings that are to be carried through this chapter. First, the knowledge of indigenous peoples is generally accepted as emerging from living in intimate relationship with a specific geographical area. It is thus a place-based form of knowing that has been accumulated over long periods of time, as Glen Aikenhead and Masakata Ogawa (2007) argue. This is perhaps best seen through the phrase 'traditional ecological knowledge' (TEK; e.g., Snively and Corsiglia 2001a, p. 6), which is commonly used in the science education research literature, although other phrases are also used such as indigenous knowledge (IK). The second idea that we will be drawing through this chapter is that IK is 'out of place' in the construction of curriculum knowledge. As such, attempts to include IK or TEK in science education curricula have resulted in what Christopher Jocks (1998) has called a caricature of the knowledge, and less than desirable outcomes for all concerned.

The Notion of Caricature

Teaching necessarily involves presenting difficult ideas simply, but in the case of complex human phenomena, such as science or culture, Julie Kaomea (2005) argues there is an ever-present danger of oversimplification. The question that arises, particularly when addressing more than one such complex issue, is whether or not an authentic representation is achieved, or even possible? In relation to the context sketched above, we suggest that both science and culture are vulnerable to simplistic representations in education, treatments usually containing embedded distortions of history and philosophy (Benson 1989; Duschl 1985). In practice, science educators frequently fall prey to such oversimplifications, as invoked, for example, by the notion of school science. In this chapter, we use the notion of caricature to refer to these inadequate treatments, focusing in particular on the caricatures of IK found in science curricula, as well as essentialising treatments of other indigenous aspects as Peter Ninnes (2004) argues, especially student identities.

The Scope of Indigenous Science Education Research

The rate of production of research literature on indigenous science education has continued to expand in the intervening decade since the first Handbook was published, to the point that a complete survey is not feasible, and the literature cited herein is representative only of the entire field – in English as well as other languages of scholarship. The relevant literature consists largely of journal articles, with a smaller number of books (Cajete 1999), edited collections (Hines 2003), book sections (Scantlebury et al. 2002), unpublished theses (Najike 2004), online articles (Michie 2003), and conference papers (Michie 2005). In the last decade there has been a proliferation in the number of specific socio-historical contexts around the globe which have become the subject of scholarship on indigenous science education. While Canada (Aikenhead 2008), Australia (Christie 2006; Fleer 1997) and Aotearoa New Zealand (McKinley 2007) have been prominent, recent studies include contexts as diverse as Hawaii (Chinn 2004), Africa (Ogunniyi 2007a, b) and Japan (Ogawa 1998). Across all the literature, the works can be divided into two categories:

1. Studies that focus on specific cultural histories, where research and development have occurred within local communities; for example, Papua New Guinea (Pauka et al. 2005), Yupiaq (Kawagley 2006) and Cree (Sutherland 2002).
2. Work with a more theoretical focus that engages in commentary and critique of a wide range of discourses, including history, philosophy, science, politics and the like, and based on documents (such as textbooks, curriculum texts and so on) or interviews (with students, teachers, trainee teachers, parents, scientists or community).

While a few articles have brought new thinking to bear, too many in both categories have tended to continually rehearse the problems. In recent years, the field has become more established with the launch in 2005 of a specialist journal, *Culture Studies of Science Education* (*CSSE*), which publishes a wide range of articles. Special issues on indigenous knowledge (IK) have been published by *Science Education* (Issue 1, 2001) and *CSSE* (Number 3, 2008), and these are used below as markers of the major debates in the field.

From Multiculturalism to Indigenous Science Education

Perhaps one of the biggest shifts for indigenous science education research has been its emergence from the umbrella discourse of multicultural science education, although philosophically they are impossible to disentangle. Derek Hodson (1999) has argued that multicultural science education is part of the wider multicultural curriculum movement, but it has generated fierce debate. The debate centres on the nature of science in science education, for which IK has been a useful example (resource) to both sides.

Contesting the Place of IK in the Science Curriculum

The *Science Education* special issue (2001, Issue 1) on multiculturalism in science education (Cobern 2001) is an example of the fierce debate regarding the place of IK in the science curriculum. The special issue featured three plenary articles by pairs of North American authors, Gloria Snively and John Corsiglia (2001a) and William Stanley and Nancy Brickhouse (2001) presenting versions of the multiculturalist argument, and Bill Cobern and Cathleeen Loving (2001) arguing the universalist case. These were followed by five brief responses from international scholars, including the author of the first chapter Elizabeth McKinley (2001), rounded out by two rejoinders from plenary authors (Snively and Corsiglia 2001b; Stanley and Brickhouse 2001). Reflecting the field overall, the research in this special issue comprised mostly discourse analysis, with few references to actual classroom data either supporting or contra-indicating the inclusion of IK in programmes of science teaching and learning. The major themes debated were as follows:

- Equity of outcomes in science education for students from non-Western cultures and the connection to historical and contemporary socio-political trajectories, including the divide between cultural imperialism and cultural relativism
- The nature, philosophy and limits of science, IK and knowledge in general, including world view theory and epistemological debates over universalism and relativism, realism and idealism, positivism and post-positivism, constructivism, postmodernism and so on
- Environmental concerns over sustainability and the possible role of IK in guiding future directions in science and its applications (i.e., IK as a correcting mechanism for science)
- Contributions of IK to the knowledge base of science (i.e., IK as a resource for science)

Discussions thus covered a wide spectrum of fields and complex issues invoked by the notion of multicultural science education. All authors included an equity argument, and furthermore, all accepted that non-Western cultures are associated with different viewpoints about reality from that of science and/or Western culture. Beyond that, the arguments and conclusions diverged widely. On one important point there was conflict between two oppositional positions: while none disputed the existence or importance of IK, only some equated it with indigenous science as a form of science different from, but equally valid to, Western science.

The emphasis on definitions reflected the tendency for meanings of key terms in the debate to vary between authors, often resulting in talking at cross-purposes, or even at different points within the same paper, which easily leads to incoherent argumentation. In their introduction, the editors cautioned that ‘authors use the word “science” by itself’ and advised the reader to ‘avoid potential confusion’ by substituting science with one of the following phrases, as appropriate: ‘nature-knowledge system’, ‘indigenous science’, ‘Western science’ or ‘school science’ (Lewis and Aikenhead 2001, p. 5). This caution highlights the importance of definitions in this field and debate. Pauline Harris and Ocean Mercier provide a pluralist perspective which assigns a wide meaning to the word science as ‘simply knowledge’ (2006, p. 145), which necessitates the use of qualifiers or substitutions, as Bradford Lewis and Glen Aikenhead suggest, to specify the meaning being invoked. This problem regarding definitions occurred not only with the more controversial or obscure terms such as indigenous science but also with larger terms, especially science and culture. The difficulty of adequately characterising such complex human phenomena often gives rise to definitions that lack substance, or focus on some aspects while neglecting others.

The problem with labelling science as a culture is analogous to that invoked by labelling IK as a science. In each case the validity of the assertion depends on a certain definition of the key term – definitions which are valid, but differ significantly from their general meanings, and those invoked in the originating problematic, that is, that students from non-Western cultures succeed relatively poorly in science education. Science educators are seldom also trained in associated disciplines, such as cultural studies (Carlton Parsons 2008; Carter 2006). Loving (1997) made the same point about the lack of philosophical expertise amongst science educators engaging in philosophical debates over the nature of science (Cobern and Loving 2008; Siegel 2001, 2006). As a result, Tony Becher (1989) contends, there is potential for disciplinary amateurs to become lost in unfamiliar territory.

The debate in this 2001 special issue thus centred on how to understand the term *multicultural science education*. Three concerns over representations of science in science education – exclusiveness, Eurocentrism and scientism – are major themes of the multicultural science education debate, as the articles in the special issue reflect. A more contentious reading understood multicultural science to imply the acceptance of non-Western cultural knowledge bases (i.e., IK) as sciences, different but equal to Western science. The logical implication was that IK could and/or should replace Western science in the science curriculum, especially for indigenous students. Two responses suggested that the philosophical arguments were irrelevant when considering real-world goals and student outcomes in science education (Svennbeck 2001; Brown-Acquaye 2001), while another suggested the political dimensions of science education for indigenous students were not satisfactorily addressed by the border-crossing approach (McKinley 2001). Two other responses, Bernard Ortiz de Montellano (2001) and Gurol Irzik (2001), addressed inaccuracies in the papers and the colonial nature of knowledge, and questioned the ethics of the multiculturalist argument, arguing that there can be no multicultural ethics of teaching without moral universalism. The responses served to highlight the trenchant nature of the disagreements between those on different sides of the debate. By the time the plenary multiculturalist authors issued rejoinders as a final step in the discussion, a certain amount of frustration was detectable in the exaggerated politeness with which the responding scholars were thanked, followed by flat contradictions of their arguments, and repetitions of the original points.

Multiculturalist scholars often counter opposing argument with allusions to (what amounts to) cultural imperialism – a seemingly potent but ultimately counterproductive strategy, which has been previously discussed and reviled in cultural politics by Edward Said (1993, p. 310).

> What invariably happens at the level of knowledge is that signs and symbols of freedom and status are taken for the reality … just to be an independent postcolonial Arab, or black, or Indonesian is not a program, nor a process, nor a vision. It is no more than a convenient starting point from which the real work, the hard work, might begin … that work [is] the reintegration of all those people and cultures, once confined and reduced to peripheral status, with the rest of the human race.

Applied to the multicultural science education debate, Said's insight reminds educators that non-Western people also have a right to benefit from and contribute to science, and that the real work, the hard work is to overcome the relative disparity in achievement for non-Western students in science education, in order for that right to be achieved. Solid decades of economic growth, and increased sensitivity to human rights, post-World War II, supported a steady improvement in education outcomes for indigenous students. As globalisation proceeded, teachers in Western countries faced classrooms of increasing cultural diversity, and anti-ethnocentrism was one aspect of the response, with teachers challenged to overcome their own deficit thinking. The contentious state of the literature in 2001 indicates that theoretical understandings remained incomplete, even though a great deal was changing at the level of practice. Innovative science education projects involving indigenous communities had begun in various places, including Alaska, where the Alaska Native Knowledge Network (www.ankn.uaf.edu) has published standards and resources for culturally responsive curricula, including science (Stephens 2003).

Setting a Place for IK in the Science Curriculum

The *CSSE* journal has adopted a less confrontational format by offering a forum of open review and encouraging authors and reviewers to have conversations about contentious issues, although some resort to the more traditional format of critique and response. The point here is that reviewers and authors can co-construct an authored piece that teases out concerns, or explores understandings in more depth. The Forum provides greater opportunities for debate of the type presaged in the *Science Education* issue reviewed above, so by comparison, this volume is even more complex and discursive, and much longer – 258 pages compared with 88. This *CSSE* special issue (2008, Issue 3) typifies the current field by including far more diverse research perspectives and contexts than in traditional science education research. In his editorial, Ken Tobin (2008, p. 536) commented on these and other issues, detailing the editorial policies, and emphasising the intent for the journal to embody an inclusive, respectful, open academic conversation and 'resis[t] a tendency to seek closure on issues', describing CSSE as 'an emerging hybrid field'.

Only three of the research articles were based on school science education for indigenous students, and each of these represented an initial foray into the field: two based on Western science teachers' doctoral research, Moyra Keane (2008) working in indigenous communities in Kwa-Zulu Natal (South Africa), and Ann Ryan (2008) in Papua New Guinea, and the third an initial report on a research collaboration between a White Canadian science educator and a Māori language teacher in Aotearoa New Zealand, Anaru Wood and Brian Lewthwaite (2008). All papers reiterated the science teacher as in the culture broker position, which has found more orthodoxy in the field, and discussed the issues raised in the 2001 *Science Education* special issue. However, none were written from evidence bases of classroom programmes based on indigenous science. Māori educators, Elizabeth McKinley and Peter Keegan (2008) and Georgina Stewart (2005), contend it is time to search for a clearer answer to the question of IK in the science curriculum, as this is required to guide real-world contexts of indigenous science education, such as Māori-medium schools in Aotearoa New Zealand.

The *CSSE* special issue also suggests that we have not progressed far with our arguments. For example, Brian Brayboy and Angelina Castagno (2008) accept the literal truth of the notion of Native science, and proceed to argue the case for including it in the science curriculum. In the course of their article and rejoinder (Brayboy and Castagno 2008b) they invoke cultural politics, citing Linda Tuhiwai Smith (1999) to articulate their position. However, they seem to create the Native science/Western science binary, against which the rest of the article argues, by pointing to the scientific practices of native peoples. Responding to Brayboy and Angelino Castagno (2008a, b), Charbel El-Hani and Fabio Souza de Ferreira Bandeira (2008), as professors of ethnoscience, fail to clearly articulate in their article why 'call[ing IK] "science" will not help' (p. 751). We can only put it down to the possibility that they have not themselves been involved in indigenous community classroom programmes based on including IK in science. Their argument 'to keep the distinctions in place when teaching and learning about science and indigenous ways of knowing' (p. 777) is thus interpreted by Brayboy and Castagno as further evidence for their own reified binary between Western science and Native science.

Unfortunately, these arguments involve an oversimplification of descriptions of key concepts that result in a caricature of IK. Brayboy and Castagno (2008b, p. 791) conclude: 'Ultimately, the disagreement with El-Hani and Bandeira appears to be that we use "science" to describe what the authors think of as Indigenous Knowledges', but this specious remark serves only to reinforce the lack of substance in the argument, and in so doing, does nothing to address the underlying educational problem. This discussion has highlighted the similarity between the oppositional positions being taken in 2008 to those prominent in 2001. While today's literature contains a wider range of voices, and the place of IK in the science curriculum is no longer strongly queried, little progress is evident in resolving the underlying theoretical questions surrounding IK and science, bearing in mind that progress is not the same as 'closure' (Tobin 2008, p. 536). Meanwhile, the crisis of poor outcomes for indigenous students in science education continues, falling through the cracks of the academic debates (Smith 1995). The following section turns to an examination of how these cracks or lacunae play out in real-world educational contexts, in high school science classrooms in Aotearoa New Zealand.

A Caricature of Culture? Indigenous Science Education in Aotearoa New Zealand

From the early 1980s, there has been a growing movement of including Māori language, practices and knowledge into the curriculum generally. This has occurred in Māori-medium and English-medium education and reflects a wider societal trend of Māori language being increasingly included in New Zealand English, and Māori knowledge and practices being included at all levels in everyday life. In a recent research project on the participation and achievement of Māori students in mathematics and science education, the authors sought the views of both teachers and students regarding the inclusion of Māori knowledge (IK) in classes (McKinley 2008; McKinley et al. 2004b). The project included four schools: three English-medium high schools with 30–45% Māori students, and an immersion Māori language school with 100% Māori students. Data were gathered from interviews with 18 teachers of science and mathematics.

Almost all the teachers in English-medium schools spoke of using IK as a resource to be drawn on in the science classroom. The resource of IK was there to fulfil two functions: to display the diversity of knowledge in science and hence to celebrate all peoples' knowledges, and to increase motivation and self-esteem of the indigenous students in the class. It is through both of these beliefs, but particularly the latter, that teachers believed increased achievement for indigenous students in science could be achieved. The following examples are used to illustrate these approaches.

In relation to issues of curriculum, the teachers spoke of Māori contexts they had brought into their lessons. Not surprisingly, all the English-medium schools in our study mentioned the same Māori contexts. These included units of work or activities on the hāngi (earth oven), kōwhaiwhai and tāniko patterns (decorative patterns for buildings, clothing, etc.), Papatūānuku (personified Earth mother deity), rongoā (Māori medicine), and the use of Māori names for native plants and the planets and constellations. For most of the teachers these contexts and activities constituted Māori knowledge and cultural values for their lessons. For example:

> In the Year 10 class Horticulture unit the students do a research project on Māori medicine or Māori uses of noted plants. […] So that's another unit that specifically targets Māori cultural values and aspects of Māori. (McKinley et al. 2004a, p. 27)

Although this uniformity of context may not be surprising, it still bears explaining why teachers in schools separated by hundreds of kilometres spoke about the same things, in answer to the question of Māori content. These contexts are well-known throughout Aotearoa New Zealand, although regional differences will exist, such as in kōwhaiwhai patterns, or plants used for rongoā.

There is a significant amount of IK associated with all of these Māori contexts teachers use in their lessons, but the purpose of their inclusion is that they have science associated with them. For example, the hāngi is often used to introduce latent heat transfer. To make a hāngi, a hole is dug in the ground, native wood is laid down and volcanic rocks placed on top, and a fire is set. When the rocks are well heated water is added, the food placed in the hole and then covered over with leaves or cloth and dirt and left to cook for several hours, after which it is dug up and eaten. It is a well-known context as hāngi are commonly used to cater for Māori, and now increasingly non-Māori, functions. Such Māori contexts are seen by a number of teachers as window dressing to the real science:

> The hāngi unit starts off nicely for the Māori students and then it gets bogged down in hard science. (McKinley et al. 2004b, p. 11)

The hāngi has tikanga (Māori protocols and practices) associated with it, not least of all who has responsibility for particular tasks and why it is used, but these aspects are dismissed by science teachers as irrelevant. The universalist view of science thus results in a superficial treatment of the cultural context.

As the teachers told us, the resources for the Māori contexts are often found in departmental schemes and unit boxes, ensuring everyone has access to these for their classes – to meet the required Māori educational outcomes.

> [S]ome of the times it looked as if it's [kōwhaiwhai] just dropped in, this was the bit you had to slide into your lesson, therefore you had met Māori education [objectives]. (McKinley et al. 2004a, p. 28)

Teachers believed Māori contexts would make the students feel better about themselves by seeing Māori culture valued in classrooms. The contexts were spoken of as a way to 'hook them [Māori students] in' and make them 'feel comfortable' (McKinley et al. 2004a, pp. 27–28). Teachers related motivation to issues of self-esteem by suggesting with Māori contexts that the Māori students became the experts and they could 'share their learning and knowledge' (McKinley et al. 2004a, p. 28). The complexity here is that teacher knowledge around IK content is weak and a number have an expectation that Māori students can become the teacher to share their knowledge. However, the reality is that many Māori students, especially those who may have lost papakāinga (tribal home) connections, feel embarrassed over their lack of knowledge.

The students we interviewed had a range of experiential knowledge of their teachers' classroom practices at including Māori knowledge into their science education. This range of experiences was correlated with a range in attitudes, whereby the students with more Māori experience (and knowledge) had stronger opinions to the effect that Māori knowledge (and language) has no place in high school science classrooms, particularly at senior levels. Our initial surprise at the emergence of these findings is echoed by the comments of the author of a well-known mathematics resource textbook based on the geometry of kōwhaiwhai patterns, which sold well throughout Aotearoa New Zealand.

> One curious pattern did emerge; sales were almost non-existent to schools which were bilingual and/or which had a very high proportion of Māori students. Feedback from teachers from those schools was sparse, but was usually along the lines of, 'it didn't meet our need'. (McKenzie 1999, p. 251)

It would appear that superficial or token attempts to incorporate Māori knowledge into science (or other areas of the high school curriculum) may only be of benefit in school situations in which Māori students feel a high degree of alienation. Māori students who are engaged more fully and have a healthier overall relationship with their school culture do not seem to feel the need for such measures, which may then be of little or no benefit in supporting their achievement in science.

Some teachers were ambivalent about whether the inclusion of Māori knowledge in science lessons worked or not, or even whether it was appropriate to do it, and voiced this resistance, even while continuing with the Māori contexts in their classes.

> We try really hard to do it more and more [teach Māori contexts] but I find it frequently backfires on me. If I try and put things in the Māori context I feel like I'm being quite false and the kids pick up on it. [...] Even ones I've taken straight out of the books the kids think it's a joke because it's coming from someone with an English accent. I will only do it if I'm quite sure that I have got it right. (McKinley et al. 2004a, p. 28)

The Māori contexts listed above, among others, are well-known and easy to name aspects of what is seen as Māori culture. However, they are caricatures because they

- Only address superficial aspects of culture (artefacts and symbols)
- Are extracted from authentic cultural contexts and hence lack original meaning, function and agency
- Are treated in isolation of the historical socio-political relationship between Māori people and Western colonial culture, people and social structures

Hāngi, and the other emblematic Māori contexts for science education, have been asked to carry a symbolic weight that is too heavy, and what gets taught under these headings is a representation of IK that is at best inadequate, and often worse.

Conclusions

Of all the countries around the world where research into indigenous science education has been carried out, Aotearoa New Zealand is a leader, which is attributable to perhaps more favourable social conditions and history by comparison with most others. It is important to clarify that this is not some claim to be better than others, but an acknowledgement that Māori is an endangered language, world view and knowledge base, in an equivocal condition that Stephen May (2001) argues is shared by many others around the globe. Clawed back from the brink of extinction, Ray Harlow (2005) shows the future of Māori is not yet secure. Other indigenous cultures have gone over the edge of complete language loss, while there are also some who have retained more traditional knowledge and practices (either with or without language) than Māori. Every cultural group follows its own unique trajectory, in response to particular sets of socio-historical circumstances. The Māori examples used in this chapter are of wider interest, but this is not to claim that our conclusions will be universally applicable to all indigenous communities.

In the last few decades, there have been ongoing attempts in Aotearoa New Zealand to incorporate indigenous Māori culture into the science curriculum both in English-medium education and through the establishment of Māori-medium schooling. However, as we have argued above, the success of these practices has been limited in terms of addressing the overall objective of equity in science education for indigenous students. Māori-medium schooling is part of the wider revitalization of an endangered indigenous language, culture and identity, but the revitalization of traditional Māori knowledge is far more difficult (Salmond 1985; Smith 2000). While this conclusion casts doubt on the current directions of indigenous science education in Aotearoa New Zealand, in the wider international context it also calls into question how IK is to be taught as part of the science curriculum.

Indigenous science education takes the postcolonial critique of Eurocentrism beyond identity politics, to the level of an epistemic challenge to science, in the form of IK. IK contains elements of those science disciplines available to pre-modern cultures, as well as explanatory narratives about the natural world, which flagrantly contravene the basic laws of science. Indigenous languages carry both identity and knowledge, but we are more successful at revitalizing identity than knowledge, whose relevance in the absence of traditional social structures has been, to all intents and purposes, lost. As we make steps to move towards the inclusion of IK in the science curriculum, such as in Māori-medium schooling, further deeper layers of cultural knowledge and practice become exposed to caricature in the form of distorted representation. The aspiration of defining and understanding IK (in order to place it in the science curriculum) can be likened to chasing the pot of gold at the end of the rainbow, which remains permanently out of reach.

It could be more productive to continue to hold the notion of IK in tension with the notion of science, as a reminder of science's own cultural origins and limitations. IK can thus be a resource of a different kind for science, by catalysing insight into the philosophical nature of science, and serving as a reminder of the many times throughout its history when the laws of science have not been adhered to, but subjected to political distortion. This understanding provides a framework around which indigenous education communities, such as Kura Kaupapa Māori, are able to construct language and curriculum policies, which best meet their long-term goals. It also puts to rest the dialectical wrangling over indigenous science (and its cognates such as Native science) imagined to replace Western science in the curriculum, and returns the focus to the lack of progress towards equity in outcomes of science education for indigenous students.

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Chapter 38
On Knowing and US Mexican Youth: Bordering Science Education Research, Practice, and Policy

Katherine Richardson Bruna

The USA shares a 2,000-mile border with Mexico. Across this border Mexicans have been moving for more than 100 years in an exchange of manual labor for economic opportunity. Because of this historical transnational connection, the lives of Mexican immigrants, even before they arrive, are enmeshed with those in the USA. More than half of adults in Mexico, in fact, have relatives in the USA. These relatives send portions of earned US wages back to Mexico in an amount that exceeds US$13 billion (Rumbaut 2006). The immensity of this transnational connection, therefore, is not to be underestimated with respect to its implications for science schooling. US Mexican[1] students study science against the context of extended family's economic dependence on their work and, by extension, their work-related knowledge and skills. Given that Mexicans are the largest Hispanic immigrant group by far – in the year 2000 they outnumbered all European and Canadian immigrants and all Asian, African, and Middle Eastern immigrants combined (Rumbaut 2006) – it is crucial to assess how much science education researchers attend to and know this transnational context and its role in the antecedent conditions, processes, and outcomes of US Mexican science teaching and learning.

Shadowed Science Learning Lives

For the first phase of my literature review on US Mexican science education, I conducted an online search of relevant articles published in selected science education research and teaching journals over the 10-year period of 1998–2008. I

[1] 'US Mexican' refers to persons of Mexican descent, whether foreign- or native-born, living in the USA.

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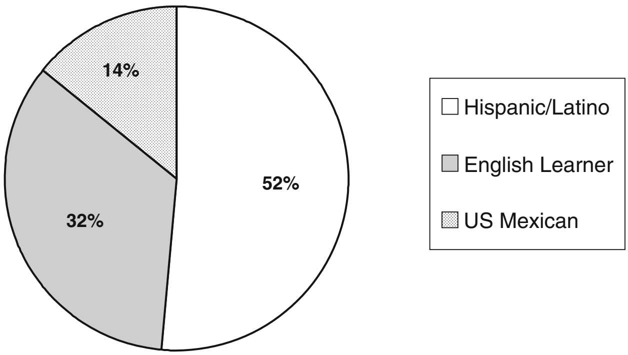

Fig. 38.1 Distribution of populations represented in selected science education journal articles, 1998–2008 (Selected journals include *Cultural Studies of Science Education, International Journal of Science Education, Journal of Research in Science Teaching, Journal of Science Education & Technology, Journal of Science Teacher Education, Life Sciences Education, School Science & Mathematics, Science & Children, Science Education, Science Scope, Science Teacher*, and *Science Teacher Education*)

used, first, the descriptors "Mexican," "US Mexican," "Mexican American," and "Mexican Immigrant" to locate articles explicitly about or involving this target student population. When this search retrieved very few (and often zero) such articles for each journal, I then used the broader descriptors of "Hispanic," "Latino," "English Learner," and "Language Minority" to search again. This substantially increased the number of retrieved articles. In reviewing this expanded pool, if I found explicit reference to US Mexican students I then included those among my target articles. I counted only research and teaching articles directly reporting on specific student experiences and contexts. This excluded literature reviews or position papers.

The results of this phase of the review process indicated an overwhelming slant in published science education articles toward populations described as Hispanic/Latino (36 articles) or English Learner/Language Minority (24 articles). Articles explicitly about or involving US Mexicans (10 articles) constituted only 14% of this subset of published research. The total distribution of articles across these populations is represented in Fig. 38.1.

For reasons described below, US Mexicans are a significant presence in US society. While research on Hispanics/Latinos and English Learners/Language Minorities can include US Mexican populations, the degree to which this ethnic group is not explicitly named as the center of scholarly efforts may indicate that they live in the shadows, so to speak, of science education's collective attention.

Out of the Shadows: Toward a US Mexican Focus in Science Education Research

While falling under the panethnic classification "Hispanic,"[2] Mexicans have a unique relationship with the USA because of issues related to size, status, proximity, and history. In 2000, persons of Mexican origin accounted for 63% of all US Hispanics (Rumbaut 2006). It is estimated that more than half of all Mexican immigrants in the USA have undocumented status (Passel 2004). These size and status issues of US Mexicans are related to Mexico's proximity to the USA as the countries share a long border that, despite US deterrents, facilitates ongoing attempts at illegal crossings. The Mexico–US border is a historically contested space, especially in the US Southwest where some Mexican families have roots that predate the annexation of land that occurred in 1848, as a result of the Mexican–American War. Because Mexican workers have filled US shortages, via official or unofficial labor importation, since before the turn of the nineteenth century, many Mexicans have long family histories that connect them to the USA.

Given the sheer size of the US Mexican population, the contextual information surrounding their schooling takes on particular significance. As Rubén Rumbaut (2006) writes: "[I]t should be underscored that aggregate statistics for the total Hispanic population reflect the predominate weight of the characteristics of the Mexican-origin population" (p. 33). In other words, research about US Hispanics is likely, without saying so, to reflect a more particular US Mexican experience. This particularity is likewise obscured by science education data collection and reporting efforts that take Hispanics, in aggregate, as their unit of identification. It has been acknowledged by the National Science Foundation itself that the goal of broadening the participation of underrepresented groups in Science, Technology, Engineering, and Mathematics (STEM) is not advanced by the aggregation of data without regard to ethnic subgroup (National Science Foundation 2004).

The particularity of the US Mexican experience is reflected in similarly particular educational antecedents, processes, and outcomes that such aggregated approaches to data collection, analysis, and reporting necessarily overlook. For example, while Hispanics, in aggregate, have the lowest rates of educational attainment of all US ethnic minority groups, it is US Mexicans who fare most poorly (US Census Bureau 2002). One explanation is found in the fact that foreign-born Mexicans have the lowest educational levels of any Hispanic subgroup and thus, in addition to challenges posed by English literacy, are less prepared to assist their children with the curricular demands of schooling. Additionally, limited experience

[2]While 'Hispanic' and 'Latino' are often used to denote the same ethnic categorization, they carry different sociohistorical connotations. Of the two, research on self-identification preferences reveals a 3 to 1 preference for "Hispanic" (National Research Council 2006, p. 4); for that reason, I use it throughout the remainder of the chapter.

with schooling also affects the way that US Mexican parents play a role in educational decision-making regarding their children. Anthony Bryk and Barbara Schneider (2002) report that US Mexican parents are more likely to defer to teachers and administrators, rarely questioning judgments made about their children.

The reality of low educational attainment as an antecedent condition among Mexican-origin families fuels teachers' low expectations for this student group influencing all aspects of educational processes. For example, US Mexican students report being happier and living up to their expectations when not with their teachers (Csikszentmihalyi and Schneider 2000). In fact, US Mexican high school students are more likely to believe that their teachers have unfavorable thoughts about them than are other ethnic groups (Schneider et al. 2006).

In terms of schooling outcomes, national performance data indicate that US Mexicans tend to score the lowest on 4th, 8th, and 12th grade tests of reading and mathematics (US Department of Education 2003). US Mexicans are least likely to take college entrance exams and apply to college (Fry 2004) with only 4% US Mexicans taking the Scholastic Achievement Test (SAT) in 2001 (College Board 2002). The dropout rate for foreign-born 16–19-year-old US Mexicans is nearly 40%, the highest of all Hispanic immigrant subgroups. While that rate drops considerably among the native born (to 15%), it still exceeds other Hispanic peer groups (US Department of Education 2000).

What is most striking about US Mexican student achievement is the observation that gains made in performance from the first to second immigrant generations do not carry into the third generation. For example, first- and third-generation US Mexicans start kindergarten with lower mathematics skills than do second-generation students and the pattern does not change over time (Reardon and Galindo 2003). This is surprising given that the third generation is characterized by higher levels of cultural assimilation. The presumption, then, that the poor educational attainment of US Mexican youth is due to a language barrier and, by extension, that attainment will be primarily enhanced by linguistically responsive instructional efforts is naive. It is this very presumption that drives the aggregated category of "English Learner" that also dominates science education research.[3] But, in fact, data on linguistic assimilation illustrate a trend toward a preference for English such that at the age of 24, 87% foreign-born and 96% native-born US Mexican youth indicate a preference for English (Rumbaut 2006). So it is not necessarily an inability or unwillingness to speak or learn English that is causing the regression in educational attainment levels in the US Mexican third-generation population. Researchers surmise, instead, that these parents and their children, having spent more time in US society and schools, could have become disillusioned with education as a path to social mobility (Padilla and Gonzalez 2001). It is this possibility that science education researchers need to more squarely address through curricular and instructional reform.

[3] The immense variability within the English Learner population leads Richard Duran (2008) to state that "ELLs are not a true demographic population… [They] are in effect a policy construction, a category of students established by individual states to satisfy their education laws" (p. 300).

Bordering Science Education Research

An examination of the articles I located explicitly about or involving US Mexican students reveals the current topography of science education researchers' attention to this important ethnic subgroup. The scope of these articles suggests the relevance of a Multiple Worlds model when it comes to research on US Mexican experiences in science schooling.

The Multiple Worlds model, proposed by educational anthropologist Patricia Phelan et al. (1991), has been used to explain differential outcomes in the schooling of adolescent youth (Fig. 38.2). The authors found that similarity between the cultural values and norms of family, school, and peer domains (students' "multiple worlds"), or significantly, students' employment of strategies to put themselves at ease despite the differences between these worlds, helped explain success. With respect to science education, Glen Aikenhead and Olugbemiro Jegede (1999) took up Phelan et al.'s work, concurring with their assertion that it is possible and desirable "to identify institutional structures that operate to facilitate boundary crossing strategies and do not require students to give up or hide important features of their lives" (p. 246). To do this requires understanding US Mexican students' experiences in, and border-crossing between, their multiple worlds.

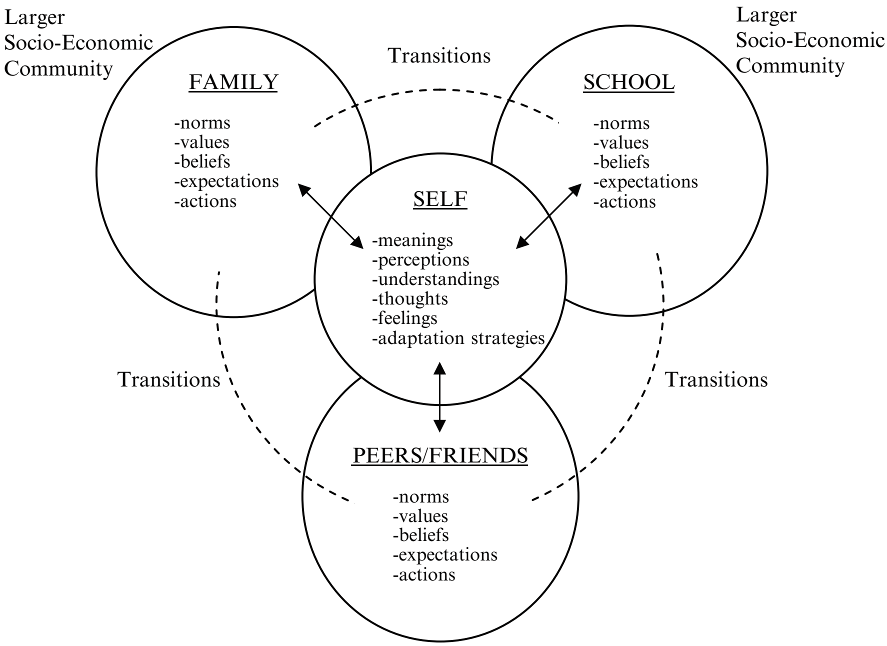

Fig. 38.2 A model of the interrelationships between students' family, peer, and school worlds (Phelan et al. 1991)

Socioeconomic Communities: The Backdrop of Poverty and Agriculture

As illustrated in the Multiple Worlds model, students navigate their movements across family, school, and peer contexts against the backdrop of the larger socioeconomic communities from which they come and in which they live. As attested to in several of the articles, the socioeconomic backdrop of poverty is one against which many US Mexican students experience science education.

For example, my colleagues and I (Richardson Bruna et al. 2007) describe a very small town in rural Mexico that is the immigrant-sending community to a specific immigrant-receiving community in the Midwestern USA. Only through this transnational capital flow (human and financial) have families in Pueblo been able to build several-roomed homes made from fabricated concrete bricks, as opposed to single-roomed handmade dirt ones, to pipe in fresh well water, and enjoy something more than a subsistence diet. Schools have yet to benefit much from the community's new resources and lack features standard to science schooling on most US campuses: certified teachers, fully-functioning media centers, print-rich environments, and textbooks. We explain that, because of this material context of poverty, newcomer students from this rural Mexican community and others like it will not be adequately prepared for the expectations of inquiry-based instruction, Internet research, and print-based information retrieval that typically characterize effective science instruction.

The poverty of such communities in Mexico is, of course, the reason for immigration to the USA. However, in coming, the driving condition of poverty is not always left behind. Angela Calabrese Barton (2001) and Richard Kozoll and Margery Osborne (2004) provide accounts of poverty in their ethnographic case studies of US Mexican students' science learning.

Most pointedly, Calabrese Barton (2001) writes of her work with two elementary-aged US Mexican girls who were living in a homeless shelter in Texas 5 years after immigrating. From her work, we learn that Claudia and Maria were aware of economic disparities between themselves, their peers, and their teacher. These disparities manifested themselves in tensions over expectations for participation in science, in this case, the teacher's expectations that the girls bring a shoe box to school for a shoe box camera. The girls expressed frustration that not only did they not have an empty shoe box at home (the expectation that they had one implies the ability to buy new shoes), but neither were they able to go to the shoe store to get one due to barriers involving their mother and what was within her means in terms of transportation, language, and child care. When the teacher offered shoe boxes, asking the girls to earn them by cleaning erasers during recess, they became angry and destructive. Claudia and Maria used this story to explain to Calabrese Barton that they "hate science" and their teacher "does not really care about [them]" (pp. 901–902).

Even into postsecondary schooling, the economic stigma associated with being Mexican in the USA remains a salient aspect of identity. Kozoll and Osborne (2004) share the story of three college-aged (two first-generation and one second-generation)

US Mexican youth who come from agricultural backgrounds. Hector, the one second-generation youth, recounts memories of racism he encountered, in the Midwest, when being followed by salespeople or being accused by his principal of stealing a car stereo. For him, success in school was about proving "we all aren't like that" (p. 163). Science played no role in that success, beyond just taking what was minimally required. He thought it was about "stupid things," asking "I don't need it in my life, for my future, so why do I have to take it?" (p. 163). The two first-generation youth, Clara and Andrea, talk very directly about how, for them, success in schooling meant creating the possibility for lives outside of communities of poverty, of lives without the instability caused by agricultural migration. For Clara, science, though not something she necessarily enjoyed, was a subject that a teacher made more exciting for her through hands-on and socially relevant activities. For Andrea, science was a subject she more actively liked as it was one place in school where she found refuge from social isolation due to socioeconomic disparity. "Through science, I got to know a few people," Andrea remarked (p. 172).

Common to most of these lived accounts of poverty is the history of agricultural work as a prevailing force in US Mexican students' experiences. The contexts from which many Mexicans immigrate are small subsistence farming communities and, in coming to the USA, agricultural work is where they, historically, have found ready employment. If their goal is to stay in the USA they are motivated, as were the students in Kozoll and Osborne's (2004) study, to create lives for themselves that do not involve the field labor of their parents. Even if their goal is to return to their agricultural communities in Mexico, as was the case with a student in one of my own ethnographic studies (Richardson Bruna and Vann 2007), they hope to do so as professionals, not laborers. Agriculture can be then a way to make science relevant to US Mexican students, in relation to either their past or future. As Kozoll and Osborne (2004) write, "[t]he argument could be made that if there is anyone who needs to know biology, chemistry, chemicals, and these 'stupid things' it is a migrant agricultural worker" (p. 163). These authors go on to talk about the lived science knowledge of agricultural workers who make decisions based on tacit understandings of growing seasons, crop timing, and other conditions, as well as the relevance of science knowledge in relationship to agriculturally related conditions, like pesticide exposure.

But my own ethnographic account (Richardson Bruna and Vann 2007) provides a cautionary tale of the thin line to be walked in making science responsive to the socioeconomic lives of US Mexican youth. My colleague and I am critical of a teacher's framing of a pig dissection activity in a Midwestern meatpacking community's English Learner Science classroom as she tells her students that the dissection will prepare them for work on the line at the local hog plant. I problematize the socioeconomic context in that community that would make such a framing possible to begin with and argue that, rather than being responsive, the framing serves to reflect and reproduce the taken-for-granted ethnic and economic segmentation of such low-skilled, low-wage labor. Discerning the difference between cultural responsiveness and reproduction of social and economic hierarchies in linking science curriculum to community contexts will be of utmost importance in effective work with US Mexican youth.

Family: The Role of Informal Educators

Against this socioeconomic backdrop, the learning of science unfolds amidst transitions between family, school, and peer worlds. Two of the articles which I located for this review (Ash 2004; Siegel et al. 2007) shed light on the role of US Mexican families, specifically their family conversations, in informal science learning.

In her research, Doris Ash (2004) examines how one first-generation US Mexican family learns science together as a result of its visits to an aquarium in California. Using qualitative analyses of observations and interviews related to two aquarium visits (six months apart), Ash documents the science thematic content with which the family was most engaged through the aquarium visit (life cycle, predation, animal vs. plant life, and taxonomic relationship), the various meaning-making resources the family used in their engagement (prior knowledge, pictures, objects, the facilitator, gestures, pointing, questioning, use of Spanish and English), and the nature of their recall. She uses the data from the family's conversations over coral to argue that the family was engaged in scientific literacy (distinguishing fact from folklore, accumulating scientific points of view, generalizing across data sets) and in the dialogic and distributed (jointly produced) inquiry and knowledge production that characterizes it. Ash concludes that family interactions in informal settings, like aquaria, can foster complex scientific understandings, troubling what constitutes the everyday, on the one hand, and the scientific, on the other.

Debra Siegel et al. (2007) also document the science conversations of US Mexican families in California, with an eye toward determining the influence of level of schooling on explanatory talk and style of interaction. Siegel et al. observed 40 US Mexican families, classified according to their mothers' high (12–16 years) or basic (3–11 years) level of schooling, as they participated in a sink or float water game facilitated by the researchers in the families' homes. From their quantitative data, they found that parents in the basic schooling group did not significantly differ from parents in the high schooling group in the ways they explained density to their children, nor did coded analyses of interaction (directive vs. collaborative vs. instructional guidance) reveal any significant differences between the basic and high schooling groups.

Both Ash (2004) and Siegel et al. (2007) attest to the active and helpful role that US Mexican families play in children's science learning. Their findings beg the question of how science schooling can leverage these families' already existing knowledge-generating interactions.

School: The Acquisition of Academic Language and Authentic Science Identity

From the informal context of home and family activity, US Mexican youth come to school. Regardless of the active and helpful support they may receive in the course of their informal science learning, the research suggests they are likely to encounter challenges in meeting the specialized language and identity demands of the science classroom. Two of the articles which I located for this review (Brown 2006; Duran et al. 1998) speak to the nature of these challenges in addition to some strategies used by science teachers to help address them.

Bryan Brown (2006) takes on the access question related to underrepresented high school students and science classroom discourse. As the teacher researcher of an introductory course at large urban school in Southern California, Brown used focus group interviews to explore students' science learning experiences with a specific eye toward the appropriation of science discourse. Six of the 29 students in his study identified as US Mexican. Brown documents US Mexican students specifically commenting on the helpfulness of the hands-on nature of their science learning. According to them, some people just learn better by "seeing things and stuff" (p. 111). He also shares US Mexican students describing how, in science, "we use a different language basically" (p. 116) and how this different language marks scientists as special. As one US Mexican student remarks, scientists use this different language "to put them at a certain level" (p. 117). These students continue to explain that this results in conflict for them because the specialized language increases the difficulty of science. "[T]he language to me is the hard part," one student says (p. 119). Brown argues that the science education community must adopt theoretical and pedagogical perspectives that help students and their teachers address this specific challenge.

Bernadine Duran, Therese Dugan, and Rafaela Weffer (1998) document their work implementing the very kind of theoretical and pedagogical changes advocated by Brown. They describe a special Saturday enrichment program for underrepresented high school students, the majority US Mexican, in an urban Midwest setting. Because of their initial findings related to difficulties these students had in identifying, expressing, and using key science content, the authors implemented a three-sequence change in instructional practice. In the first or receptive phase of instruction, the authors used diagrams to help students identify target content and ventriloquate or mimic, teacher talk. In a more expressive phase of instruction, students were encouraged to use concepts for their own purposes. In the final, more interpretative phase of instruction, students analyzed real-life experience using acquired conceptual resources with the aim of displacing the teacher's science authority with their own responsibility for science meaning-making. The authors' work suggests that US Mexican students do benefit from approaches to instruction that explicitly attend to the ways a configuration of particular linguistic resources construe particular meanings in science.

While not attending to science discourse per se, Irene Rahm, John Moore, and Marie-Paule Martel-Reny (2005), in their work with a community-based science program for first-generation students, describe how the authenticity of hands-on science learning provided in a biochemistry lab resulted in an enhanced science identity for US Mexican student, Edric. As opposed to the quick experiments of science classrooms, the mentorship in the lab allowed him to see that science is about confronting and resolving unanticipated problems. As he worked with a team to improve a pain-relieving drug, Edric came to understand science within its larger social context and to connect himself personally to the outcome of his science activity. Expressing how he would feel if the drug were to make it out onto the market, Edric comments on his "bragging rights" and how "that'd be cool" (p. 6). This resonates with what Calabrese Barton (2001) found in her work in the after-school science program. The same girls, who expressed being alienated by their science learning in school, developed an expanded sense of science agency when encouraged to experience science learning in genuine relationship to their lives' concerns. Work that began with a simple biology-based caterpillar project evolved, out of student interests, into something more akin to architectural engineering. Calabrese Barton documents how the youth she worked with navigated the constraints imposed on them by their residence within the homeless shelter. They advocated for the construction of movable planters that would allow them to move the butterflies to an acceptable outside location once they emerged and were no longer allowable inside. In the case of one youth, she also advocated for the building of a desk from the planter material, at which she could study (since she did not already have one). Calabrese Barton describes the youths' activities as providing them with a transformed understanding of the meaning of science learning and identity, mentioning particular measurable outcomes such as the application of concepts such as scale, measurement, and spatial relations all in service of their own life-based objectives.

Taken together, these articles clearly indicate the need, within science education, for explicit attention to the challenges posed by academic language to US Mexican students. Similarly, given what these articles suggest about the distance students experience between themselves and science discourse and practice, efforts to target academic language acquisition should be contextualized within meaningful hands-on activity so that the relationship between specialized language resources and the respective uses to which they are put in science is authentic and not artificial.

Peers/Friends: Relationships in School and Science

While not centrally treating the theme of peer- and friend-group involvements and their implications for science learning, several of the articles I located for this review provide insight into the ways in which these relationships may significantly influence, in positive or negative ways, science schooling outcomes for US Mexican youth. Kozoll and Osborne's (2004) interviews with the three students in their research attest to the extent to which they made sense of their schooling experience as unique when considering the high dropout rate among their US Mexican peers, friends, and, indeed, family; as one of these students, Hector, said in referring to his experience in Texas schools: "[N]ot that many people graduated so that's why I stood out" (p. 162). This same student goes on to explain that his success in school was motivated by a desire to disprove the stereotypes associated with his ethnic group: "They think all Mexicans are on welfare and they all have low paying jobs and they're uneducated and that's not true" (p. 163). The story of another of these students, Clara, speaks to the importance of extracurricular activities and, by extension, their associated peer groups, in providing her with opportunities for relationships with people very different from those of the community from which she came, opportunities she readily embraced. On the other hand, Andrea speaks to the real challenges posed by socioeconomic differences between her and her peers in school. But, for her, these differences were somewhat leveled through the shared activity of inquiry that the science classroom provided.

The formation of these kinds of academic, social, and intellectual identities among university engineering students in California who were women of color, and among them those of US Mexican heritage, was the subject of a study by Erika Tate and Marcia Linn (2005). Using an interview-based methodology, these authors found that the institutionalized STEM-oriented peer support networks offered by the university were helpful in the early years of college. However, in all cases, they did not completely satisfy students' social needs. Students reported on the importance of their participating in social groups consisting of members with shared racial/ethnic identification. The salience of racial/ethnic identity is clear when a US Mexican student comments on the difference between her high school and university environments: "My high school's like 99% Mexican. So, I come here and it was very different… it was hard to interact with Asians or Whites because I wasn't used to it" (p. 488). The authors note that this implies that both official academic peer networks and more informal ethnic peer organizations have equal roles to play in promoting persistence among underrepresented students on college campuses.

Two of the articles provided a glimpse of what peer/friend relationships actually look like when enacted within a science-learning setting. From Calabrese Barton's (2001) work, we see how one way that Maria and Claudia understood their friendship was through their shared dislike of science. It was their "secreto de las niñas" [girls' secret] (p. 900). These girls found communion in their shared socioeconomic positionings as science outsiders in not being able to comply with the teacher's shoe box request. In protest of such positionings and to let the teacher know of their dislike for science, these girls, as Calabrese Barton describes, consciously decide not to raise their hands in class. It is to transform the meaning of science and as a result their science learning identities that Calabrese Barton engaged these girls and their peers in the more authentic activities of her after-school program. Ultimately, she argues, their expanded science-learning agency needs to be understood within the expanded sense of individual agency, as persons acting within and on the world, that participation in an authentic community of science practice afforded.

The story of Claudia and María resisting the camera shoe box science activity because of their marginalizing positioning finds a parallel, again, in my own account (Richardson Bruna and Vann 2007) of high school English Learner Science students' reluctance to do the meatpacking-framed pig dissection. While not as explicit about a conscious intention to withdraw from class activity, the authors' my account shows newcomer students clearly expressing disinterest not only in participating in the dissection activity but in the teacher's framing. In addition to his peers' more subtle expressions of displeasure, one student, Juan, flatly states, "Yo no carnicero [I'm no butcher]" (p. 42). As the activity proceeds, the account also shows other peers' different ways of taking up the teacher's framing; these students talk amongst themselves about their work as butchers in Mexico and jokingly compare their dissection work to the preparation of traditional pork-based Mexican dishes. One student, Augusto, goes to great lengths to make the teacher aware of his extensive knowledge of pigs, gestation, and miscarriage from his life in Mexico, work he hopes to continue through continued agricultural studies that can benefit his community. I assert it is, in fact, Augusto's insistent counter-example to the teacher's initial framing of the pig dissection as relevant to his life in ways far beyond that of his family's work at the meatpacking plant, which ultimately leads the teacher to provide him and his peers with a more authentic science framing for the activity. That eventual framing concludes that body systems are complicated, that animal dissections allow us to learn more about them, and that there are ethical questions surrounding their use. In this way, I, like Calabrese Barton, document the way in which peer groups react to science classrooms as places that reproduce, within their walls, the hierarchies of the larger society, while also pointing to how peer groups can play supportive roles in trying to create different science learning places premised upon different social positionings.

On Knowing and US Mexican Youth

The quantitative results of my research review suggest the paucity of efforts, within the field of science education, to know about the particular learning experiences of US Mexican youth. Given that US Mexicans are the largest nondominant ethnic group in the nation and that 42% of them are under the age of 20 (Durand et al. 2006) and thus theoretically in school, this indicates that the field does not currently have the capacity to effectively address the curricular and instructional needs of many teachers and students. The directions future research efforts should take clearly emerge, however, from the qualitative review. As suggested by the Multiple Worlds model, the science learning experiences of US Mexican youth are configured across a variety of informally and formally based relational domains, each providing its own set of challenges and resources. Science education researchers would do well to attend to each of these domains, explore their interconnections, and comprehend how they construe particular ways of science knowing and activity. While the same is true of every science learner's experience, it is critical to pay concerted attention to the particularity of the US Mexican experience as part of efforts to increase access to and representation within the sciences because of the societal implications of their continued poor performance.

As Rubén Rumbaut (2006) points out, 69.7% of Mexican-born workers labor in the lowest paid jobs of the US economy. This situation, he continues, "has profound implications for the social and economic prospects of their children's generation, and it is also the basis for common stereotypes that disparage and stigmatize the population as a whole" (p. 58). Science education has a crucial role to play in reworking this current social arrangement by redistributing science knowledge, identity, and socioeconomic power. What Patricia Gándara (2006) says about the societal benefits of higher education is true for science: "When [science] education is curtailed for a population group because of systematic impediments to their intellectual advancement, then both the individual and the society are impoverished" (p. 235). Dismantling these impediments, these borders to opportunity, will require science education researchers to do some border crossing of their own – away from their work with more familiar populations and domains and into new worlds, both in the US and Mexico, of student communities, classrooms, families, friends, and peers.

Such work promises to advance theoretical and methodological approaches to knowing US Mexican youth in ways that have important political and pedagogical payoffs. For example, researchers are learning more about the validity and reliability limitations of such standardized tests when used with culturally and linguistically nondominant students. There is growing evidence demonstrating systematically varied heterogeneity in performance among EL groups, suggestive of an interaction between the test and the knowledge and skills associated with particular ethnic backgrounds (Duran 2008). This is a potent example of the way in which discerning the particularity of the border crossings made by US Mexican youth into school science will become increasingly particularly important.

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Chapter 39
Science Education Research Involving Blacks in the USA During 1997–2007: Synthesis, Critique, and Recommendations

Eileen Carlton Parsons, James Cooper, and Jamila Smith Simpson

In the mid-1990s in the USA, equity by way of the slogan "science for all" became more prominent in science education discourse. Debates, efforts, and research on how to achieve equity in science education ensued. In this chapter, the authors review research studies in science education involving one US group for which equity has historically been and continues to be an issue. The authors review investigations from 1997 to 2007 involving Blacks, a general term used to denote African-Americans who are individuals with an African ancestry directly linked to the founding of the USA, and Blacks who are individuals of the African Diaspora who immigrated to the USA. The authors synthesize the literature and discuss the relevancy of the literature corpus to the status of US Blacks in science education.

The chapter contains five major sections. The first section details the selection of studies. The second and third sections describe the more recent context of US science education. In the fourth section the authors present a synthesis of the science education research and the usefulness of the research in relation to the status of Blacks in science education is the focus of the final section.

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Literature Identification

Using the terms "Black" and "African-American," the authors thoroughly searched science education research journals with impact factors that placed them among the top 100 journals in education and educational research journals in the Social Science Citation Index. The impact factor represented the average number of times articles from a specific journal published in 2005 and 2006 had been cited in 2007 Journal Citation Reports (JCR). JCR calculated the impact factor by dividing the number of citations in 2007 by the total number of articles published in 2005 and 2006. The JCR list of 100 education and educational research journals included the following science education research journals: *Journal of Research in Science Teaching*, *Science Education*, *International Journal of Science Education*, and *Research in Science Education*. Because research published in the previously listed journals frequently cited research from the *Electronic Journal of Science Education*, *School Science and Mathematics*, and *Cultural Studies of Science Education*, the authors also searched these journals. Additional journals searched by the authors included *International Journal of Science and Mathematics Education*, *Journal of Science Education and Technology*, *Journal of Science Teacher Education*, and *Journal of Women and Minorities in Science and Engineering*. These searches produced 70 articles.

Context of Recent Science Education Reform in the USA

At the national level, current reform in science education is embedded in a standards-based movement (Vinovskis 2009). This movement is rooted in the 1983 National Commission on Educational Excellence report, *A Nation at Risk* (National Commission on Excellence in Education 1983). As the movement evolved, the federal government's influence on state education policies, including policies related to science education, increased and the broad goals espoused in the science education reform documents of the 1980s were reflected in state curricula as subject area learning standards.

In 1985, the American Association for the Advancement of Science (AAAS) launched Project 2061. Described as a long-term initiative to alter precollege education in specific academic disciplines, Project 2061 developed two documents that impacted curricula, *Science for All Americans* (American Association for the Advancement of Science (AAAS) 1989) and *Benchmarks for Science Literacy* (AAAS 1993). These documents emphasized content knowledge and skills necessary for developing a scientifically literate society.

During the administration of President George H.W. Bush, federal and state policy-makers took the first tentative steps toward full-scale standards-based reform. In 1989, Bush called together the nation's governors for a 2-day conference. The conference produced six national education goals dubbed "America 2000." These goals included one that would bear directly on the evolving standards-based movement that would highlight competencies in specific subjects in grades 4, 8, and 12 (Nelson et al. 2006).

Two distinct groups initiated efforts to define competence in a subject area. First, the US Department of Education provided grants to national organizations to assist in the development of national standards in core academic subjects. In 1996, the National Research Council (NRC) published the *National Science Education Standards* (NSES). These standards, which shared Project 2061's focus on scientific literacy in the USA, featured inquiry teaching, professional development, assessment, program development, and science education as a system. Second, through its Goals 2000 legislation passed in 1994, the presidential administration of Bill Clinton provided federal funds to support the states' development of their own teaching and learning standards for core subjects. Forty-seven states and the District of Columbia applied for the Goals 2000 funding (United States Department of Education 1998). State standards for science were strongly influenced by NSES.

In 2001, under the administration of George W. Bush, the Elementary and Secondary Education Act (ESEA) was revised (Vinovskis 2009). Known as "No Child Left Behind" (NCLB), ESEA shifted the burden of standards-based reform squarely on the shoulders of the states. In order to receive some form of federal support, particularly those designated for students living in poverty, states were now required to develop academic performance standards for K–12 students in core academic subjects including science. In addition to these standards, states were required to develop one statewide accountability system to determine if schools and school districts were achieving yearly benchmarks of adequate progress in core subjects. Finally, ESEA also mandated that test scores be disaggregated so that the achievement disparities between racial, ethnic, and socioeconomic groups would be visible to educational stakeholders.

The revision of ESEA has been criticized for its emphasis on standardized test scores as the sole measure used to hold schools and districts accountable. Further, the law has been condemned for its punitive measures, the loss of federal funding and transfer options for unsatisfied families, for schools and districts that fail to meet their state's definition of adequate yearly progress. Science educators have argued that the reforms resulting from NCLB have harmful consequences to both students and teachers. Prior to 2007 – the year in which testing in science was mandated to begin – science instruction was sometimes sacrificed to reading and math instruction and standardized test preparation. The emphasis on standards and test preparation also deprofessionalized teachers' work, reducing it in some cases to a nearly scripted experience (Settlage and Meadows 2002). Finally, the reform movement has been condemned because of its one-size-fits-all approach to teaching and learning. This is particularly true of students from marginalized groups and students living in poverty (Crocco and Costigan 2007). In the midst of over two decades of reform that promoted quality science education for all, the status of Blacks in US science education remains abysmal.

Status of Blacks in Science Education

The relative position of Blacks as a collective to other groups in the USA is evident in the economic and education domains of US society. Statistics indicate that in 2006, Blacks comprised 12% of the US population but had the greatest percentage living in poverty; 24% in contrast to 8% for Whites, 8% for Asians, and 21% for Hispanics of any race (United States Bureau of the Census 2007). These disparities not only exist in economics, but also in education.

Generally, the quality of science teachers is determined by the number of years of teaching experience, the extent of undergraduate and graduate science coursework, and performance on teacher licensure examinations (Young 2005). Teachers with 5 or more years of experience, who have undergraduate or graduate degrees in the subjects in which they teach, and whose performance on certification examinations exceeds a specified cutoff score are considered teachers of acceptable quality. Richard Ingersoll (2002) found that teachers with less than 5 years of teaching experience, who have less than an undergraduate minor in the areas in which they teach, and who are not fully certified in their assigned areas comprise the teaching workforce in high-poverty and high-minority schools. High-poverty and high-minority schools are defined as schools with student populations of 75% or more from economically disadvantaged backgrounds and of students of color, respectively (National Center for Education Statistics (NCES) 2007). Blacks were more likely to attend such schools.

Statistics also show that many Blacks are more likely to be placed in lower-level science courses and that Black males are more likely to be found in special education classes and less likely to be found in gifted and advanced science courses (Atwater 2000; Rascoe and Atwater 2005). Research typically characterized the instruction of science courses taught in the standard or low academic tracks as back-to-the basics with drill and memorization as both the means to and ends of learning (Gilbert and Yerrick 2001). In the instances in which Black students enrolled in advanced science courses or specialized science classes, they reported unwelcoming environments marked by negative perceptions, low teacher expectations, little encouragement, strained teacher and student interactions and relationships, and various personal and institutional challenges to meaningful learning (Brand et al. 2006; Griffard and Wandersee 1999). Additionally, racial disparities in the offering of advanced placement (AP) courses in science in relation to the ethnic makeup of schools have been documented. Daniel Solorzano and Armida Ornelas (2004) documented that schools that had high enrollments of Black students were less likely to offer AP courses and schools that provided AP courses offered few of them. In 2007 Black students who made up approximately 14% of graduating seniors comprised about 6% of AP examinees in biology, around 6% in environmental science, and 4% in chemistry (College Board 2008).

The status of underserved students and their success regarding AP exams are areas of concern for the College Board. The College Board (2008) defines an equity and excellence gap, a case in which the percentage of underserved students who have access to and success on the AP exam is less than the percentage of underserved students in the entire class of 2007. The College Board examined all 50 states and the District of Columbia in relation to an equity and excellence gap for Black, Hispanic, or Native American students. The College Board found that 17 out of 51 sites eliminated an equity gap for Native American students, 15 eliminated an equity gap for Hispanic students but only one out of 51 sites eliminated an equity gap for Black students (College Board 2008).

As denoted in the synopsis of the status of US Blacks, Blacks as a collective have limited access to quality science education (Hewson et al. 2001) which goes beyond shared physical space highlighted in the desegregation and civil rights legislation (Tate 2001). From 1997 to 2007, a portion of science education research conducted in the US involved Blacks. What areas did these studies investigate? What additional insights beyond the statistics on the status of Blacks in US science education can be gained from these studies?

Synthesis of the Literature

Using the purposes of studies, the authors divided the investigations into several categories. Articles comprising the three largest categories are presented here. In this section, the authors synthesize the literature under subheadings that reflect the categories.

Studies of Students' Perceptions and Attitudes

These studies, which were divided into two groups, investigated students' perceptions about scientists and their attitudes toward science. The first subset of these articles situated the significance of students' perceptions and attitudes in the students' future choices regarding science. The second set examined perceptions among different subgroups of students.

As part of the first subset of articles, Janice Terry and William Baird (1997) highlighted the low number of women in science elective courses and careers. They examined high school students' attitudes toward women in science with respect to 17 variables. They found statistically significant and positive correlations among the students' attitudes toward women in science and mothers' nonscience occupations, science plans, education level plans, careers in science, female influence at school, female influence on future planning, and female influence regarding a science career. With respect to the variance in students' attitudes toward women in science, gender accounted for most of the variance followed by science ability, level of education the student planned to complete, and career interest outside of science. Shannon Gilmartin et al. (2007) extended investigation of the attitudes toward women in science factor beyond attitudes and examined how the percentage of female science faculty was related to high school students' perceptions, achievement, views, self-concept, and college major aspirations. The results indicated that the percentage of female faculty in high school science departments was not related to students' perceptions and stereotypical views of science, students' science self-concepts, and students' college major aspirations. Keeping in line with this focus on gender in science, Eileen Parsons (1997) studied Black high school females' images of the scientists and discussed these culturally influenced images as windows to self-concepts and future career choice. With regard to students' images of the scientist, Jason Painter et al. (2006) examined the impact of students' interviewing of scientists involved in a multiyear project on nano-scale science. They found that the interviews helped to alter students' perceptions of scientists as male, always in a lab coat, only doing experiments, being weird/ boring, and always working alone; this alteration in perception remained 1 year later. The last study of this subset that couched the significance of students' attitudes and perceptions in decision-making explored course enrollment decisions in relation to gender and students' learning experiences in contexts classified as high and low learning cycle classrooms (Cavallo and Laubach 2001). In classrooms where learning cycle instruction was salient, significantly more females planned to enroll in science elective courses, and males, had higher science enjoyment, and viewed science as more gender inclusive.

The second set of articles that investigated students' attitudes and perceptions looked at differences among subgroups of students that explicitly included racial/ ethnic comparisons. Douglas Huffman et al. (1997) studied students' perceptions of learning environments among different groups of students within the same science classes. The results showed that Black students perceived classes as less involving than White students. Faye Neathery (1997) examined the correlations of students' attitudes toward science with gender, race/ethnicity, ability, grade level, and science achievement and found statistically significant relationships for gender, ability, grade level, and science achievement; a significant relationship was not found for race/ethnicity for the large sample in which all non-White students were grouped together as minority. Like Neathery (1997), Sheldon Woods and Lawrence Scharmann (2001) classified non-White student participants into one group for an analysis that focused on high school students' perceptions of evolutionary theory in relation to science locus of control, logical reasoning ability, race/ethnicity, gender, grade level, and teacher. Statistically significant correlations were used to determine the order for entry into a forward regression analysis of which race/ethnicity, gender, grade level, and teacher did not meet the criteria. Logical reasoning accounted for 10% and science locus of control for 1% of the variance in students' perceptions of evolutionary theory.

Impact Studies

The studies classified as impact studies examined the effects of curricula and instructional strategies on various student outcomes. Student outcomes ranged from achievement to social activism, with most studies examining achievement. The foci of many of these studies examined curricula and instructional practices that aligned with science education reform advocated in NSES.

In a large-scale quasi-experimental study that involved the professional development of teachers in standards-based science teaching and their implementation of such teaching, Jane Kahle, Judith Meece, and Kate Scatlebury (2000) found that standards-based teaching positively influenced the achievement and attitudes of

African-American students who attended urban schools. Similar results emerged for curricular interventions. For example, the enactment of inquiry units during the teaching of a state's science curricula improved student achievement not only in terms of recall but also in the comprehension of specific content knowledge (Singer et al. 2003); in the acquisition of certain inquiry skills (Keselman 2003; Keys 1998); in relating scientific concepts (Rivet and Krajcik 2004); and in the ability to transfer the scientific understanding to new situations (Fortus et al. 2005). Some researchers also examined the effects of interventions on the achievement gap among different demographic groups. Sharon Lynch et al. (2005) in their study of a curriculum intervention did not find a narrowing of the achievement gap among demographic groups but noted that for groups not utilizing the curriculum the gaps appeared to widen. In contrast, Okhee Lee et al. (2005) who examined curricula and instructional practices reported a narrowing of the achievement gap among different demographic groups at the end of the school year during which the study was conducted. Other studies showed that specific tools or teaching methods positively influenced outcomes of interest. These studies featured broad approaches like the use of science, technology, and society (STS) to more specific methods like using descriptive drawings.

An STS approach to teaching global warming indicated that more students expressed awareness of social activism more frequently after STS instruction but the approach failed to alleviate difficulties of 5th graders in conceptually understanding the topic (Lester et al. 2006). Kellah Edens and Ellen Potter (2003) found statistically significant differences on posttests that assessed students' conceptual understanding of the law of conservation of energy under three learning conditions. One condition involved explanatory text accompanied with journal writing, another highlighted explanatory text with illustrations that students reproduced in their journals, and the last condition used explanatory text with drawings students generated. The learner-generated drawing and the drawing reproduction groups scored significantly higher than the writing group. In a similar vein, Linda Cronin-Jones (2000) examined students' conceptual understanding and attitudes toward ecology in three different instructional conditions. Students received no instruction, traditional instruction (guided reading, lecture, demonstrations, discussions, role playing, indoor lab activities, slide and film presentations), or experimental schoolyard instruction (guided reading, lecture, demonstrations, discussions, role playing, outdoor lab activities, and field observations). Analysis of variance yielded significant effects for content knowledge and attitude posttest comparisons. The mean content knowledge posttest scores of the experimental outdoor group were higher than the traditional classroom group who significantly outperformed the "no instruction" group. Post hoc comparisons indicated that the attitude posttest scores were significantly more positive for the experimental and traditional groups in comparisons to the control group; however, the mean attitudes posttest scores for the traditional and experimental groups did not differ. In addition to examining changes in conceptual understanding, Robin Ward and James Wandersee (2002a, b) explored the impact of Roundhouse diagramming, a visual organizer, on metacognition and performance as measured by grades. Students utilizing Roundhouse diagramming improved in the aforementioned domains. Related to investigating the effects of tools and methods on conceptual understanding, one study explored what kinds of authentic, real-world situations are inquiry-rich and science-content-rich for students (Lee and Songer 2003). Another study examined the relationships among genetics content knowledge, moral reasoning, and argumentation quality (Sadler and Donnelly 2006), of which a significant contribution of content knowledge and moral reasoning to variations associated with argumentation quality was not found.

"Creating Space" Studies

With respect to science teaching and learning, science classrooms are cultural interface zones (Norman et al. 2001) where the cultures of schools, teachers, students, and science interact. Stacey Olitsky (2007) examined successful classroom interactions within these cultural interface zones. These interactions were marked by entrainment, a common rhythm and mood that increased positive feelings about group membership. The participants shared a mutual focus, engaged in side talk, and actively contributed to group solidarity. In his study of interactions in two teachers' classrooms, Kenneth Tobin (2006) described both successful and unsuccessful interaction rituals. Unsuccessful interaction rituals rather than successful ones are more typical for Black students in US science classrooms. Often, cultural interface zones are sites of conflict for these students (Norman et al. 2001).

The conflicts that arise in cultural interface zones in the science classroom have many different manifestations. For example, in their investigation, Maria Varelas et al. (2002) explored the connecting interfaces of three genres, recognizably organized social activities in which all participants contribute. They unearthed through the students' genres of rap songs and plays, the tensions surrounding affect and thinking about science content; teacher-instituted structures that comprised classroom genres; and the science genre that consisted of students' uses of various tools and lab activities. Other studies featured the teachers' and students' management of these conflicts. In Gilbert and Yerrick's (2001) study, student–teacher negotiations of these tensions influenced the quality of science instruction in the participating rural science classrooms. In response to the tensions, students developed identities that worked against academic achievement. Similarly, other studies documented conflicts among the identities students constructed of themselves as science learners and the identities they developed within their homes and communities (Brown 2004; Brickhouse et al. 2000). The previously surmised conflicts within the cultural interface zones in the science classroom necessitate cultural border crossings (Aikenhead and Jegede 1999). The articles classified as creating space studies investigated various vehicles or boundary spanners (Buxton and Carlone 2005), material and symbolic, used to facilitate border crossings into school science.

Jhumki Basu and Angela Calabrose Barton (2007) used funds of knowledge, practice-based cultural understandings of a community that have accumulated over time, to facilitate border crossing. Basu and Calabrose Barton (2007) investigated the connections among students' funds of knowledge and their sustained interest in science. Students exhibited a sustained interest when there was a strong connection between science and authentic opportunities that advanced students toward their visions of their own futures; a strong correspondence between science and students' views of science as useful; and a strong link between science and environments that nurtured relationships that reflected the values of their communities. To uncover the students' funds of knowledge, several studies employed cogenerative dialogues.

Cogenerative dialogues are critical discussions that are structured to engage participants in sharing. Christopher Emdin (2007a) used cogenerative dialogues to elicit students' perspectives on corporate (i.e., notions of achievement defined by benchmarks via standardized testing) and communal practices (i.e., science as a social activity and ideas of success linked to students' ways of knowing and being) in relation to their engagement and success in science. Emdin (2007b) then identified students' out-of-school communal rituals and supported their enactment within the science classroom which enabled the students' success in science and navigation of existing corporate structure and corporate rituals that dominated schooling. Emdin (2007a, b) employed cogenerative dialogues as an elicitation tool to uncover students' funds of knowledge that were then used to facilitate the students' cultural border crossings. In contrast, Gail Seiler (2001) used cogenerative dialogues as a direct means to border crossing. In cogenerative dialogues, students used their own discourse patterns to engage in science talk. This sense of ownership, illustrated in the use of the students' own discourse patterns in Seiler's (2001) study, became a tool to facilitate cultural border crossings in the final two studies of the "Creating Space" Studies section in this chapter.

Rowhea Elmesky (2005) and Rowhea Elmesky and Kenneth Tobin (2005) used a documentary production project with students in order to make science their own. As a part of the process of producing the documentaries and the science content of the documentaries, the students contextualized the scientific abstractions within their cultures as specific embodied practices. In the manifestations of high-energy levels, rhythm, singing, and dancing, the students collectively reproduced and enacted their own culture as a vehicle to understanding scientific concepts. Consequently, students expressed a value in participating in science either as a prerequisite or corequisite in achieving their personal aspirations.

Critique and Recommendation

An extensive search of 12 science education literature sources over a span of 10 years produced a total of 70 articles that explicitly identified Blacks or African-Americans as participants in research studies. Of the 70 articles, authors of 51 (73%) of the articles provided racial/ethnic information explicitly (e.g., numerical breakdown) or implicitly (descriptors in the journal title or findings) for the study samples and 21 (30%) disaggregated results by race/ethnicity. The majority of the studies that identified the race/ethnicity of participants used the identifier "Black." Although the synthesized literature provides some insights on the status of Blacks in science education, two primary constraints exist.

First, in relation to the corpus of studies in science education for the past decade, 70 studies is a relatively small number of projects involving Blacks. Similar to the indictment made against reform that promotes science for all, the small number of studies involving Blacks utilized a one-size-fits-all approach. The studies' findings were presented as though they were equally relevant and valid for all participants in the study, regardless of the status of the group to which they belonged. By default, the findings of these studies were most pertinent to the group that comprised the majority of the studies' samples of which a subset included a Black majority. In these cases where the majority of the study participants were identified as Black, significant differences that exist among collectives of the African Diaspora who immigrated to the USA and African-Americans, a collective with an African ancestry directly intertwined with the founding of the USA, were not acknowledged. Failing to distinguish among non-Blacks, African-Americans, and individuals of the African Diaspora who immigrate to the USA inadequately portrays the challenges encountered both by African-Americans and African Diaspora immigrants (Lehner 2007).

Second, with the exception of a few investigations, the studies did not address phenomena in relation to conditions specific to Blacks. In his critique of NSES, Alberto Rodriguez (1997) discussed the invisibility of students from diverse groups in the text despite numerous photographs of diverse students throughout the document. This invisibility critique is also relevant for historical and contemporary science education reform in the USA and the vast majority of science education research involving Blacks.

Even in light of the previously described constraints, the science education research involving Blacks provided information that can prove useful in improving the status of Blacks in US science education by way of science education reform. With regard to what should be addressed in science education reform, the studies on students' perceptions and attitudes described factors that may curtail or encourage students' participation in science. With respect to what may constitute science education reform, the impact studies indicated that some curricula and instructional implementations improved achievement and reduced the achievement gap among different demographic groups. In relation to how to tailor science education reform to address the needs of different groups so it can work to achieve science for all, the creating space studies provided insights on how to mediate various conflicts that may hinder Black students' involvement in and learning of science. On the one hand, the studies indicate progress; on the other, they signify the very difficult work that lies ahead.

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Chapter 40
Social Justice Research in Science Education: Methodologies, Positioning, and Implications for Future Research

Maria S. Rivera Maulucci

To evaluate trends in social justice citations, I searched for the phrase "social justice" using the online search fields in each of the following journals: *Journal of Research in Science Teaching*, *Science Education*, *Research in Science Education*, *International Journal of Science Education*, *Journal of Science Teacher Education*, *Elementary Journal of Science Education*, and *Cultural Studies of Science Education.* My search identified 105 journal articles, including empirical studies, literature reviews, book reviews, editorials, and forums spanning 1981–2008. I searched within each journal article for each social justice citation. Out of the 105 articles, 66 had a single mention of the phrase and in 29, social justice only appeared in the references list in the title of a book or journal article. Studies with a single social justice citation in the references list were eliminated from further review. The most frequently cited text (13 citations) was *Teaching Science for Social Justice* (Calabrese Barton et al. 2003).

Figure 40.1 shows a breakdown of the number of articles and the number of times the phrase "social justice" was cited in the text of the journal article for the remaining 76 articles. For example, there were 39 articles with one in-text citation, and one article with 46 in-text citations of this phrase. This analysis shows that very few articles addressed the topic of social justice throughout the paper.

Figure 40.2 shows the distribution of the number of articles that included at least one in-text citation of social justice by year. In 1977, for example, there was one journal article that cited social justice and in 2008 there were 22 articles. This analysis shows that the concept of social justice is gaining some traction in the field of science education research, with the number of articles citing the concept increasing over time.

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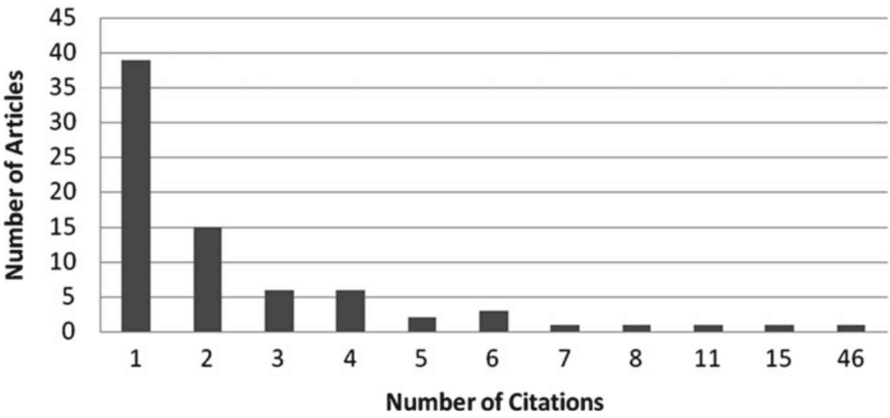

Fig. 40.1 Number of articles by number of in-text citations

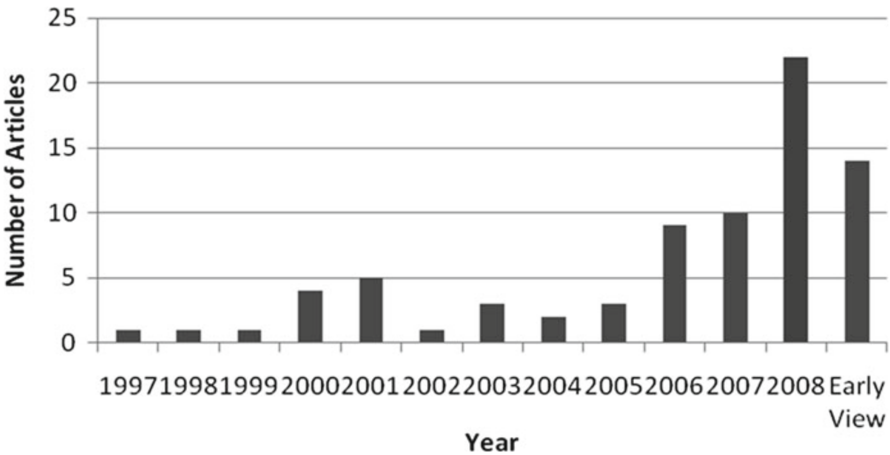

Fig. 40.2 Social justice citations by year

Figure 40.3 shows the distribution of articles by journal citing social justice. *Cultural Studies of Science Education* had the largest number of citations, with 33 articles that included at least one in-text reference to social justice, followed by the *Journal of Research in Science Teaching*, with 14 articles.

The above analysis indicates social justice is an idea that is gaining some traction among members of the science education community. However, a close look at the studies reveals a tendency for authors to list social justice alongside equity as an overarching goal. Other studies clearly align theoretically and methodologically with a social justice framework; yet, this alignment is not made explicit in a consistent way. Thus, social justice in science education remains a concept that requires further definition and theorizing. In the following section, I review three early studies of social justice in science education.

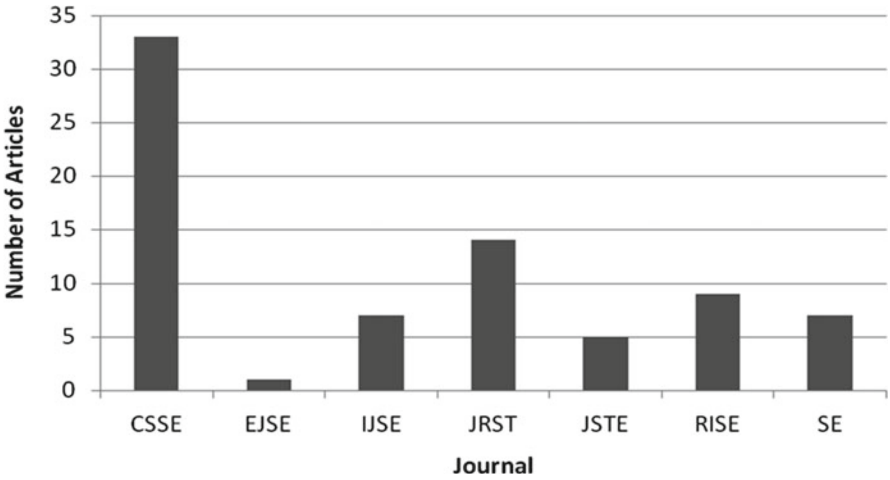

Fig. 40.3 Social justice citations by journal

Early Framing of Social Justice in Science Education

One of the first scholars to write about social justice in science education was Alberto Rodriguez (1997), who published a critique of the National Science Education Standards in JRST. He argued that the standards document engaged in a discourse of invisibility because it did not provide a clear argument for why or how teachers should work to improve the achievement of traditionally marginalized groups of students – women, the poor, and students of First Nation, African, and Latino/ethnic background. Rodriguez wrote:

> In the case of education reform, an individual's political will must come from a clear sense of purpose and understanding that social justice requires one not only to question, but to take action even when these actions may lead to transforming one's own comfort and institutionalized privilege (or lack of it). (pp. 28–29)

Rodriguez provides a critical analysis of trends in student achievement across gender and ethnicity, drawing on data from the National Assessment of Educational Progress (Mullis et al. 1994) to highlight inequitable outcomes. He concluded that the standards should provide "more visible theoretical frameworks and arguments in support of learning science for understanding and for teaching science in more inclusive and multicultural ways" (p. 32).

Angela Calabrese Barton (1998) takes up the issue of social justice from the perspective of what it means to teach science for all with homeless children. Calabrese Barton explores issues of representation and identity in science and demonstrates that when youth have the power to shape science for their needs and interests, the borders of science expand. Calabrese Barton explains: "The doing of science involved merging the emotional with the physical and intellectual. The students found their experiences with the ugliness of their community or with hunger as important and more complex than science could describe in its neutral language" (p. 391). At the same time, blending activism with scholarship requires the researcher to navigate relationships and ethical issues. For example, Calabrese Barton shared the following:

> In an initial interview with a leader and activist within the local social services community, I was told that this research project was not only a commitment to research, but also to the children, and that "unless I was on my death bed," I had better not miss a scheduled visit. I recognized that I had begun to earn Gilma's trust simply by returning each week to spend time with her and the other children. (p. 385)

Calabrese Barton concludes: "If *all* students are to participate in science in genuine ways, then teachers need to find ways to value the diverse ways of knowing brought to class by the students" (p. 391, emphasis in original).

William Kyle (1999) aligned teaching science with teaching for social justice. In an editorial for a theme issue focused on science in developing countries, he noted:

> The totality of an education in science is equally as much oriented toward social justice, critical democracy, empowerment, action-taking, and investing in our future's intellectual capacity as it is about constructing conceptual understandings of the world. (p. 255)

Kyle recognized that beyond a way of knowing about the world, science education could be a way of acting in the world to transform it:

> Education is about hope, dreams, aspirations, and struggle. … Education must be *for* something. But what? Education ought to be for the purpose of fostering critical and participatory democracy, enabling students to recognize that the world that is being presented to them is in fact a world that is being made – it is changing constantly – thus, for this very reason, it can be changed, it can be transformed, and it can be reinvented. (p. 256, emphasis in original)

Further, he argued that social justice in science education could foster the types of global communication and collaboration that could address issues of poverty, development, and sustainability in the world.

The above articles position science education and science education research as tools and contexts for challenging injustice. In the remainder of this chapter, I review five studies that illustrate some of the ways social justice research balances needs for scholarship with needs for activism in the field. I will explore each author's positioning with respect to social justice and their particular social justice issue. Then, I will analyze the methodological approaches used in each study. I recognize that this focus might marginalize other scholars whose work incorporates a social justice framework. However, I believe a more focused review will provide a clearer justification for further research and highlight ways to strengthen the reporting of social justice research in science education.

Positional Identity and Social Justice Research

To understand positioning, I draw on the idea of positional identity, as "understanding how social markers such as race, class, gender, religion, among others, influence views of teaching and learning science" (Moore 2008a, p. 593). Just as the standards

Table 40.1 Foundations of social justice research in science education

Discourse	Central ideas
Feminist	• Urges rethinking the nature of science and science education • Proposes liberatory rather than oppressive science education • Positions knowledge as subjective and contextually mediated • Shifts away from compensatory programs
Multicultural	• Challenges notions of science grounded in the Western tradition • Urges use of culturally relevant and responsive pedagogy and science for self and social transformation • Emphasizes role of community action
Critical	• Critiques the role of schools and institutions in reproducing inequity • Highlights the role of hegemony, power, and privilege in sustaining oppression • Critiques enculturation and reproduction of the dominant culture • Struggles to address entrenched inequalities
Science for all	• Positions scientific literacy as a national goal • Asserts equity goals in science education • Clarifies the nature of science • Emphasizes inquiry-based methods for science teaching and learning

engage in a discourse of invisibility (Rodriguez 1998), science education research also engages in a discourse of invisibility when it does not convey an adequate understanding of the researchers' agendas or the ways their positional identities frame how they perceive and work to address social justice issues. Since social justice research blends scholarship and activism, researchers also position themselves with respect to the theory and practice of social justice and the particular social justice issues addressed by the project. Thus, researchers may also position themselves in relation to discourses, texts, issues, people, and places.

Social justice research in science education has its roots in feminist, multicultural, and critical approaches to science education and takes up the challenge of science for all in ways that position science as a dynamic, contextual tool for promoting equity and empowerment (Rivera Maulucci 2008a). Table 40.1 summarizes some of the central tenets that inform work in social justice in science education. Rather than providing an exhaustive list, the table conveys the idea that the ways researchers position themselves with respect to these and other discourses, provides for multiple, nuanced, situated, and emerging definitions of social justice in science education.

For example, Rodriguez (1998) provides a clear sense of his positionality through the following statement:

> As a Latino science teacher educator, I am deeply committed to closing the gap in student achievement and participation, as well as to making science more socially relevant and accessible to all children. (p. 590)

He explains that, "in the secondary science methods class that I teach, I am the only Latino and the only member of a typically underrepresented ethnic group in the sciences" (p. 603). Rodriguez situates his work within discourses related to multiculturalism and equity in science education:

> It is not enough just to encourage all learners to celebrate and study the contributions of men and women from various ethnic backgrounds to the advancement of scientific knowledge. Multiculturalism seeks to provide learners with opportunities for empowerment. (p. 591)

He draws on critical, multicultural, and sociocultural theories of education and learning to propose sociotransformative constructivism (STC) as a way to teach for diversity and understanding, and notes that "the STC orientation provides spaces where existing contexts can be collaboratively transformed to meet social justice goals. Power, then, is a central construct in STC – power is the currency of social change" (p. 599). In this case, the social justice issue is framed by his position as a science teacher educator in a program that seeks "to prepare teachers to work respectfully and effectively with children from diverse backgrounds (i.e., from diverse socio-economic status, cultures, ethnicities, abilities, sexual orientation, family units, and so on)" (p. 593). Rodriguez clearly states: "This is an ideological orientation based on a principle of social justice in which I personally believe" (p. 590).

In her article, Felicia M. Moore (2008b, p. 595) positions herself as a science educator:

> As a science educator, I am always open to new approaches to my teaching and research. Over time, I have become interested in not only what I do in my teaching but also how it informs and provides a space for research.

Moore defines social justice work in science education as attending to students' right to learn science (Tate 2001): "Social justice considers action toward developing learning environments that support all students in learning, such that every student has a right to learn and to have a quality education" (pp. 589–590). And she explains further:

> By taking on social justice education as a science educator I challenge preservice teachers to understand what it means to create science classroom communities with access, equity, quality, and opportunity to learn science as fundamental goals. (p. 591)

Moore situates "learning about social justice for preservice teachers … within the context of multicultural education" (p. 591). She also highlights the need for preservice teachers to understand issues of power and privilege in education, how social structures and hierarchies marginalize students, and how preservice teachers might deconstruct such social structures through their practice (Lewis 2001). Her definition of agency draws on critical and multicultural perspectives:

> [F]or this study, agency is defined as individuals or groups reflecting, acting, modifying, and giving significance to the teaching of science in purposeful ways, with the aim of empowering and transforming themselves and/or the conditions of their lives, students and others … it is the way that teachers use power, influence, and science to make decisions that effect positive social change in science classrooms. (p. 591)

One way in which Moore could have strengthened her positioning in this study might have been to include the ways her race, ethnicity, and gender influence her positioning with respect to social justice in science education and the ways her positioning with respect to critical and multicultural theories frame her vision of science.

In my study, I address the issue of English language learners (ELLs) and science education (Rivera Maulucci 2008b). Through an in-depth case study of a preservice teacher, Elena, I undertake a critical exploration of school policies and procedures that render native language proficiency as a deficit that immigrant students must overcome. In the study, I position myself as a teacher educator in a social justice teacher education program concerned with the question of how, "social justice teachers [can] be prepared to meet the challenges of supporting immigrant youth in a climate that increasingly calls for immersion…" (p. 18). I reveal my personal positioning with respect to the issue of language, as I argue against school policies that do not allow immigrant students to maintain their native language and culture:

> What would I have chosen? As a third-generation Puerto Rican, speaking English at home, and divorced from many of the trappings of culture that enable one to fit in–the language, idioms, dance, music, and modes of dress – I have lived in a borderland between Puerto Rican and not Puerto Rican. What would I have chosen? I would have chosen science *and* Spanish. (pp. 36–37, emphasis in original).

My positioning with respect to critical and multicultural discourses comes through examination of US immigration patterns that favor elites and assimilationist ideologies that undergird school language policies and equate "science for all" with "English only." For example: "Such policies cannot be neutral; rather they confer privilege and access to standard English, scientific discourse, and bilingualism, differentially across race, class, and ethnic categories, as well as immigration status" (p. 41). I argue that we cannot understand the case of Elena without situating her microlevel experiences in the classroom within mesolevel structures of schooling for ELLs and macrolevel patterns associated with globalization. My positioning with respect to the issue of language would be strengthened by a discussion of the demographics of students in my teacher education program and the schools we partner with, to highlight the need for preservice teachers to develop strategies to support ELLs.

Edna Tan and Calabrese Barton (2008) indicate their position with respect to global feminism: "Global feminism is a phrase we use to describe the ideas emerging from the most recent wave of feminist scholarship attentive to transnational and globalization issues while drawing upon critical, anti-racist and postcolonial perspectives" (p. 46). In their study, Tan and Calabrese Barton focus on urban, Latina girls' participation in science:

> We believe that by paying careful attention to how and why urban girls author identities-in-practice, we can gain deep insight into the noncommodified forms of knowledge, relationships and activities that girls often employ to participate in science related communities in ways that are culturally and socially just and sustainable. (p. 46)

Their study conveys a clear positioning with respect to the research context, with detailed descriptions of the school, the principal, the science teacher, and the neighborhood. However, the authors do not share how their own gender, class, race, or ethnic identifications impact their positioning or how they navigated their insider/outsider status as social justice researchers from an elite college working in a high-poverty community.

Rowhea Elmesky and Kenneth Tobin (2005) address the issue of urban youth's social capital in contrast to the deficit models that dominate how policy-makers, schools, teachers, and the educational reform literature typically construct the problem of underachievement in inner city schools:

> We contend that the trends of science education in urban settings will continue if theoretical frameworks of cultural poverty, deprivation, and social reproduction continue to inform research. We find these theories to be hegemonic – laden with deficit views of marginalized youth and with a static view of culture. Moreover, these theories reinforce the cycles of oppression experienced by the urban poor … (p. 809)

Their critical perspectives are clear in their attention to issues of power and hegemony. Elmesky and Tobin also position themselves with respect to current science education research by highlighting how their approach "challenges traditional views" (p. 811) by engaging youth as researchers. Their social and cultural positioning is established in an endnote that states: "The first author is from a mixed racial background, yet has been enculturated to some extent with white, middle-class value systems. The second author is white" (p. 825). On the one hand, they seek to share methodologies that provide for a more inclusive understanding of student agency in research; however, their positionality in terms of gender, ethnicity, race, and class and how that impacts their relationships with the youth is framed by the labels, insiders and outsiders. For example, "When Ken began to teach science in an inner-city high school, to afford his roles as teacher educator and researcher, he quickly realized that he needed insider perspectives to inform his practices" (p. 813). In a similar way, they wrote: "Although we wanted to learn more about student researchers' homes and neighborhoods … we could not ignore the fact that we would be outsiders in those fields …" (p. 816).

Critical Ethnography in Social Justice Research

A methodology is a theory of method and as such encapsulates epistemological, ontological, tactical, and catalytic assumptions. For example, as a researcher, I employ critical narrative inquiry methodology (Rivera Maulucci 2008b). Critical narrative inquiry rests on the epistemological assumption that people come to know the world and its power relations through story. From an ontological perspective, the researcher attends to narrative elements, including character, setting, events, dialogue, action, emotions, and time. Critical narrative inquiry views storytelling as a meaning-making experience, both for the participants, as they tell their stories, and for the researcher, as they interpret and retell stories to advance theoretical and analytical points. Telling, interpreting, and retelling stories, changes or transforms participants and the researcher in ways that implicate the need for further personal or contextual change. Critical narrative inquiry also foregrounds a need for tactical authenticity, in that the research process empowers participants and the researcher to act on the need for change. In essence, social justice methodologies encapsulate assumptions about how people individually, collectively, and contextually, come to know and change the world and each other.

All the studies in this review employ critical ethnographic methods. What makes these studies critical is their focus on issues of power and the need for transformation. For example, according to Moore (2008b): “Research grounded in critical methodologies is particularly suitable for understanding preservice teacher identity, agency and stance toward social justice because it seeks to document the process of empowerment” (p. 590). Elmesky and Tobin (2005), assert: “A critical research process invokes a goal of determining the existence of injustice, finding methods for altering it, and identifying the sites for transformation” (p. 810). Ethnographies typically: (a) focus on a particular context; (b) employ multiple research methods, such as interviewing, participant observation, and collection of artifacts to explore a wide range of social behavior in the setting; (c) use grounded theory approaches to data analysis; and d), are marked by prolonged engagement and an understanding of complexities, rather than generalizations (Pole and Morrison 2003). Thus, critical ethnography rests on the assumptions that knowledge is situated, that it requires an insider’s perspective, and that participants’ perspectives matter. Furthermore, Rodriguez (2001) proposes “catalytic validity” as “a way of conceptualizing our research as valid by the degree to which participants and researchers have substantially improved their condition as a direct result of their involvement in the study” (p. 345). Bringing the need for transformation together with the need to understand participants’ perspectives on change requires researchers to negotiate their activist role in the field. Relationship-building, dialogue, trust, and continued negotiation play central roles in maintaining a course of activism that remains responsive to the needs, hopes, and desires of the participants alongside needs for scholarship.

For example, to meet the challenge of preservice teachers’ ideological and pedagogical resistance, Rodriguez (1998) plans and implements four strategies of counter-resistance: the dialogic conversation, authentic activity, metacognition, and reflexivity. His year-long ethnography begins with 18 preservice teachers during their methods course and continues with four students during their student teaching assignments. He triangulates multiple data sources, including ethnographic field notes, course evaluations, and student-produced artifacts from the class, interviews, focus group notes, videotapes of two lessons during student teaching and notes from discussions of the videotaped lessons. Throughout the report, it is clear how Rodriguez advocates for the need to teach for diversity and understanding through an STC orientation. He summarizes some of this advocacy as follows:

> In short, the strategies for counterresistance discussed thus far consisted of providing students with authentic activities in the methods class to bring their taken-for-granted beliefs into the open. This was followed by in-depth discussions of critical readings and activities that allowed them to consider alternate points of view. Next, the members of the focus group were placed in schools where they were able to explore the applicability of their metaphors of teaching and learning in various school contexts. (p. 609–610)

In a similar way, Tan and Calabrese Barton (2008) engage in a year-long ethnographic study of 6th grade, urban Latina girls. Their long-term work with the case-study teacher and students situates the study as intervening in the world to enhance girls' participation in science. Tan's advocacy is evident as she assists the teacher in preparing materials for lessons, coteaches some of the lessons, interacts with case-study girls during the lesson, debriefs lessons with the teacher, and helps brainstorm ideas for subsequent lessons. Thus, teaching for social justice involved the collective effort of students, teacher, and researchers to promote opportunities for girls to author identities-in-practice. Tan and Calabrese Barton conclude:

> [P]aying attention to who girls are, who they want to be and the relationships that are important to their science learning – aspects of science education which are decidedly non-commodified and un-economic in focus – can open up the dialogue around Science for All. (p. 64)

Elmesky and Tobin (2005) share their evolving approaches to working with youth as student-researchers over a 5-year period. In addition to traditional forms of data-gathering, such as interviews, classroom observations, and journals, the youth created unique artifacts, such as a science-related movie and rap videos. Importantly, the creation of these artifacts required youth to develop technical and theoretical expertise, and afforded the youths agency in the day-to-day practice of research. Elmesky and Tobin explain that:

> … we have developed new windows into the lives of urban youth, to contest the privileging of our voices as the adult, university-based researchers and so as not to put forth claims rooted in our own experiences of research, teacher education, and teaching and learning of science…. (pp. 810–811)

Moore's (2008b) study seeks to understand how preservice teachers' conceptions as change agents relate to their science teacher identities. She closely analyzes the coursework of 23 students and follow-up interviews with five students. In the course, students read *Ways with Words: Language, Life, and Work in Communities and Classrooms* (Heath 1983), engage in small group dialogues, and wrestle with ideas of diversity, teacher identity, and science teaching. A final, individual reflection paper addresses "their ideas about issues of diversity and teaching science in urban classrooms; identity as an agent of change; and worries, fears and issues about science teaching in urban elementary classrooms" (p. 593). The study is based on the epistemology that preservice teachers come to know themselves as potential science teachers through their interactions with texts, dialogue with others, and classroom experiences. Finally, in my study (Rivera Maulucci 2008b), across Elena's narratives from her schooling experiences as an immigrant acquiring English, through preservice field experiences in an international high school that serves predominantly English language learners, her emotions emerge as commentaries upon her enduring concerns (Archer 2004) related to issues of language, power, and identity. The study draws on interviews and coursework, including field journals, reading responses, teaching autobiographies, and fast-writes across three semesters of Elena's participation in a teacher education program. I use a metalogue, a written dialogue between Elena and me at the end of the study, to share the educative and transformative value the study had for Elena.

The Road Ahead: Implications for Future Social Justice Research

Individually and collectively, the above studies contribute to several key implications for future social justice research in science education. First, the social justice framework should be evident throughout the study. Social justice should comprise an overarching goal of the research, drive the conceptual framework, inform the methodology, methods, and analysis of the data, and frame the implications and conclusions. Second, the researchers' subjectivities, or vested interests in the outcomes of the project and the findings of the research, should be made evident. Researchers should indicate their positional identities with respect to social markers that might have bearing on how they frame social justice issues or science education. They also should articulate a clear positioning with respect to the major discourses that contribute to social justice perspectives, including critical, feminist, and multicultural theories, and science for all.

Rather than a universal or monolithic understanding of science, a social justice lens situates scientific literacy as a collective endeavor shaped by the needs and interests of the community and developed through social relationships and interactions. Whether the study focuses on girls authoring identities in practice, preservice teachers preparing to teach for diversity and understanding, or youth engaged in the role of researchers, the meaning of scientific literacy is contingent upon the needs and interests of the participants. By employing methodologies sensitive to the collective needs of all stakeholders, reports of research can indicate the contradictions and how they are negotiated during the research process. Future research should highlight the researchers' social and theoretical positioning. In this way, a social justice perspective shifts the focus from science as a body of knowledge and skills to be learned on its own merits, to a social activity that students, teachers, teacher educators, and science education researchers engage in for the purpose of personal and community understanding and transformation.

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Part V
Assessment and Evaluation

Chapter 41
Student Attitudes and Aspirations Towards Science

Russell Tytler and Jonathan Osborne

Students' attitudes towards science have been a topic of enduring interest in the field of science education for over 40 years – but why? After all, there is no sense in which people are concerned about students' attitudes towards the learning of English or history. So what is it that drives the interest in this topic? The brief explanation is that compulsory science education bears a dual mandate (DeBoer 1991; Millar and Osborne 1998). On the one hand, school science is charged with educating the next generation in and about science – an education which essentially requires developing an understanding and appreciation of the explanatory hypotheses that science offers of the material world, how these came to be and why they matter. On the other hand, school science has a responsibility to educate the next generation of scientists. Whilst there are overlaps between the two goals, the former requires a broad overview of the domain. The latter requires a foundational knowledge of the discipline and its major concepts. And it is the supposed failure of school science to engage sufficient students in studying science for a future career that has pushed students' attitudes to the fore as a matter of concern for society and policy makers. Most advanced societies look to science and technology to sustain their economic lead, particularly in the context of threats to the dominance of the Western world posed by the developing economies of Brazil, Russia, India, and China. Looked at in this manner, science education is seen as a pipeline which supplies the next generation of scientists, albeit a leaky one. Sustaining the throughput of this pipeline is very much dependent on the attitudes that school science and science engenders in its students. Given a mounting body of data which suggest that students' attitudes in advanced societies are either negative or declining (Tytler, Osborne et al. 2008),

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there is a considerable interest in their measurement and any causal insights which might inform ways or remediating what is perceived to be a problem. This is true, for instance, in the UK (HM Treasury 2006), the USA (National Academy of Sciences: Committee on Science Engineering and Public Policy 2005; National Commission on Mathematics and Science Teaching for the 21st Century 2000), Australia (Tytler, Osborne et al. 2008) and Europe (European Commission 2004).

Meaning and Assessment of 'Attitudes'

Before discussing what the research findings reveal about student attitudes or what might be their causal factors, it is important to explore what is meant by the first construct in the title of this chapter. Perhaps the most important distinction here is that drawn by Leopold Klopfer (1971) between 'attitudes towards science' and 'scientific attitudes'. The latter are a set of attitudes which are the product of working in science and which are a commitment to evidence as the basis of belief, a belief in rational argument and a scepticism towards hypotheses and claims about the material world. Such values are represented by Robert Merton's (1973) attempt to define the principles that are inherent to science, commonly known as CUDOS: results are the property of the community not the individual (communalism); results are not specific to a context but universally valid (universalism); scientists should maintain a neutral or disinterested perspective about the acceptance of their findings (disinterestedness); research claims must be novel (originality); and all claims should be subject to criticism (scepticism). Merton's analysis has been substantively challenged by the body of work undertaken in the social studies of science, including Harry Collins and Trevor Pinch (1993) and Helen Longino (1990), who have questioned the validity of each of these claims in the light of the historical record and contemporary studies of scientific practice.

However, it is the first of these two constructs, 'attitudes towards science', which is the focus of this chapter and the body of research discussed here. Attitudes towards science is a complex concept which, at one time or another, has embodied the following concepts:

- The display of favourable attitudes towards science and scientists
- The display of favourable attitudes towards school science
- The enjoyment of science learning experiences
- The development of interests in science and science-related activities
- The development of an interest in pursuing a career in science or science-related work

It is necessary to distinguish between attitudes towards *doing* school science and attitudes towards science *in general*. It is the perceptions of school science, and the feelings towards undertaking a further course of study, which are likely to be most significant in determining students' decisions about whether to proceed with further study of science beyond compulsory courses. Students' attitudes to science more generally can be quite different from their attitudes to the science that they experience at school (Lindahl 2007).

The construct is further complicated by the fact that what is commonly measured is an attitude towards a unitary concept of 'science', whereas secondary schooling differentiates the object (which is the focus of the attitude) into three (physics, chemistry and biology), if not four sciences (earth sciences as well) which students like differentially according to research (Havard 1996; Lyons 2006; Osborne and Collins 2001). In attempting to measure one or more of these constructs, studies have incorporated a range of components in their measures of attitudes towards science, including:

- Perceptions of the quality of the science teacher
- Anxiety towards science
- The value of science
- Self-esteem at science
- Motivation towards science
- Enjoyment of science
- Attitudes of peers and friends towards science
- Attitudes of parents towards science
- The nature of the classroom environment
- Achievement in science
- Fear of failure in a course

The two key constructs in developing and assessing an instrument for the measurement of attitudes are the instrument's reliability and its validity. The latter is essentially dependent on a well-developed theoretical argument for the constructs that are to be measured. Without some careful elaboration of what is being measured and why those particular constructs might be considered important, it is likely that disparate items could be put together in a unitary scale for which there is no theoretical justification. The problem of interpreting the significance of a unitary construct synthesised from these multiple components of attitudes towards science has been clearly identified by Paul Gardner (1975), who comments:

> An attitude instrument yields a score. If this score is to be meaningful, it should faithfully reflect the respondent's position on some well-defined continuum. For this to happen, the items within the scale must all be related to a single attitude object. A disparate collection of items, reflecting attitude towards a wide variety of attitude objects, does not constitute a scale, and cannot yield a meaningful score. (Gardner 1975, p. 12)

And, if there is no single construct underlying a given scale, then there is no purpose served by adding the various ratings to produce a unitary score. As Gardner (1975) argues, weight, length and height can all be measured meaningfully, but adding these three variables together to form some kind of 'dining table index' simply produces a meaningless, uninterpretable variable.

Establishing the validity of an instrument, however, is not a simple task. Construct validity is reliant on the extent to which the items being measured have a good theoretical foundation so that it is clear what it is that the instrument is attempting to measure (Messick 1989). One means of attempting to establish construct validity is to use a panel of experts and ask them individually what aspects they think the items are attempting to test. However, this has been criticised by Hugh Munby

(1982) as it rests on an assumption that the meanings attributed to the items by the experts will be the same as that attributed by the participants. The latter is essentially what is termed face validity – that is, whether the construct which is operationalised in the items written to assess it has the same meaning for the participants as it does for the researchers. The only means of testing this is to conduct interview studies with a selection of participants to explore what they understand the item to be asking and the reasons for choosing the response that they did. However, a not unreasonable argument here is that items of the nature 'you have to be clever to do science' or 'I often do science experiments at home' are really only open to one interpretation and, hence, do not require validation using such methods; this might explain why it is difficult to find attempts at such validation in the literature.

Reliability is generally sought by using the psychometric principle of writing several items which are attempting to measure an underlying unitary construct such as 'interest in science'. A good instrument needs to be both internally consistent and unidimensional (Gardner 1975). Internal consistency is commonly determined through the use of a measure known as Cronbach's alpha coefficient and is often quoted in much of the research literature on the measurement of attitudes. Essentially what this does is measure the extent to which individuals who score highly on any given item also score highly on the other items thought to be assessing one specific construct. However, it does not follow that scales which are internally consistent (i.e. all the items have a Cronbach alpha in excess of 0.7) will be unidimensional. This is because a scale might be composed of several clusters of items, each measuring distinct factors. In this situation, as long as the responses to every item correlate well with the other items, a high Cronbach alpha will still be obtained even though what is being measured is not a single unitary factor. Hence, it is important that the unidimensionality of scales is tested by using an appropriate statistical technique (e.g. factor analysis) that is capable of resolving the underlying factors. If a scale does measure what it purports to measure, then all the variance in responses should be explained by a loading on a unitary factor. Such a factor analysis also enables the establishment of convergent and divergent validity in that theoretically similar items should converge (i.e. correlate) and theoretically dissimilar items should diverge (i.e. not correlate). Moreover, those items that converge should match self-evidently with the theoretical concepts from which they were originally derived or used in their formulation (Henerson et al. 1987).

Evidence that the field has had problems in developing instruments which meet these criteria comes from a recent comprehensive review conducted of 66 instruments for measuring attitudes by Cheryl Blalock et al. (2008). Twenty of these measured attitudes towards science and were assessed against the criteria of: the extent to which they were theoretically grounded; what tests had been undertaken of their reliability; the measures that had been used to establish their validity; how the dimensionality of the instrument had been used in reporting the scores; and the extent to which the instrument had been tested and developed prior to its use. Using these criteria, the authors reported that the highest scoring instrument was that developed by Paul Germann (1988) where 'reliability estimates were in the 0.90s, and various methods of validity evidence were given including content, discriminant, convergent, contrasting groups, and exploratory factor analysis' (Blalock et al. 2008, p. 970). The factor analysis used supported a one-dimensional structure and total scoring was used appropriately. Yet this instrument has only been used in a single study. In contrast, instruments which score poorly on their criteria, for example, Richard Moore and Frank Sutman's Scientific Attitude inventory (Moore and Sutman 1970) have been used in 13 additional studies. What Blalock et al. points to is the tendency for researchers not to use existing instruments, but rather to reinvent the wheel each time by designing one anew and, then, not subjecting it to the kind of development required of a good psychometric measure. The practice of reusing non-validated instruments has clearly hindered the development of methods and expertise in this field.

Some recognition of these criticisms can be found in more recent work. For instance, the instrument developed by Per Kind et al. (2007) does define the constructs that it is attempting to measure and establishes its reliability and validity through the use of a factor analysis which demonstrates that the factors correspond to the theoretical constructs it seeks to measure and that they are internally consistent. Likewise, Steven Owen et al. (2008) have re-evaluated one commonly used instrument – the Simpson-Troost Attitude Questionnaire (Simpson and Troost 1982) which consisted of 59 items. Using a sample of 1,812 participants split into two groups – half of which were used for exploratory factor analysis and half for confirmatory factor analysis – using only 22 items, they were able to reduce the instrument to a 5-factor model which they identified as: the extent to which the science class was motivating; the level of effort that the student applied to their own learning; the influence of family models; the extent to which it was enjoyable; and a measure of the influence of their peers on their liking for science. In doing so, they have addressed many of the criticisms that might be made of earlier work and have refined an existing instrument.

In coming to a view either about existing instruments or developing their own, researchers therefore need to ask:

- Whether clear descriptions have been articulated for the constructs that one wishes to measure
- Whether separate constructs have been combined to form one scale and whether there is evidence that these constructs are closely related, in order to justify such an action
- Whether the reliability of the measure has been demonstrated by confirming the internal consistency of the construct (e.g. by use of Cronbach's alpha) and by confirming the unidimensionality (e.g. by using factor analysis)
- Whether validity has been demonstrated by the use of more than one method, which includes the use of psychometric techniques

Failure to do any one of these would mean that the work would not be meeting the standards now established in the field and would weaken the validity and value of the findings.

In the more advanced studies, such factor analysis is used as a basis for structural equation modelling to identify the latent variables and how the factors interrelate. Well-known models are:

- The Eccles Expectancy-Value Model (Eccles et al. 1983), which focuses on students' engagement in terms of how a task is valued (or not) and their expectancy of success.
- Albert Bandura's (1997) model that emphasises perceptions of self-efficacy, which are beliefs in whether individuals can perform the behaviours necessary to achieve a required outcome. Bandura argued that such beliefs are a major determinant of an individual's activity choice and their willingness to expend effort and motivation. This work has proven powerful in explaining individual's motivation and engagement and has been used in major studies exploring, for instance, career choice (Bandura et al. 2001a, b).

However, of themselves, attitudes might not necessarily be related to the behaviours that a person actually exhibits (Potter and Wetherell 1987). For example, a pupil might express interest in science, but avoid publicly demonstrating it amongst his or her peers who regard such an expression of intellectual interest as not being the 'done thing'. In such a case, motivation to behave in a particular way might be stronger than the motivation associated with the expressed attitude or, alternatively, anticipated consequences of behaviour could modify that behaviour so that it is inconsistent with the attitude held.

Consequently, it is behaviour rather than attitude that has become a focus of interest and which has led researchers to explore models developed from studies in social psychology. Icek Ajzen and Martin Fishbein's (1980) theory of reasoned action – which is concerned fundamentally with predicting behaviour – is one such model. This model focuses on the distinction between attitudes towards some 'object' and attitudes towards some specific action to be performed towards that 'object' (e.g. between attitudes *towards* science and attitudes towards *doing* school science). Ajzen and Fishbein argue that it is the latter kind of attitude that best predicts behaviour. Their theory represents a relationship between attitude, intention and behaviour. Behaviour is seen as determined by intention, and intention is a joint product of attitude towards the behaviour and the subjective norm (i.e. beliefs about how other people would regard one's performance of the behaviour). The theory of reasoned action has been applied to some attitude and behaviour studies in science education. For instance, Frank Crawley and Annette Coe (1990), Tom Koballa (1988) and Steve Oliver and Ronald Simpson (1988) have all found that social support from peers and attitude towards enrolling for a course are strong determinants of student choice to pursue science courses voluntarily, which suggests that the theory has at least some partial validity. The effect of attitudes on behaviour has been a particular focus of interest in the field of research on environmental education, with Joe Heimlich and Nicole Ardoin (2008) providing a useful review of the main theoretical ideas and empirical studies.

There are numerous other methods of measuring attitudes. *Interest inventories* provide a common technique in which respondents are presented with a list of items and then asked to identify the ones in which they are interested. The Relevance of Science Education (ROSE) study (Sjøberg and Schreiner 2005) used such an approach in trying to identify which topics in science about which children were interested learning. However, such inventories are generally restricted to their specific focus, yielding only a limited view of what might or might not be formative influences on attitudes to science.

Enrolments in science subjects are another major source of data of increasing concern. However, any attribution of significance to such data as a sole measure of interest in science is questionable, as subject choice can be highly affected by changes in society that affect the structure of economic opportunities, the desire not to foreclose opportunities, the perceived difficulty of the subject and, particularly in the case of boys, the association of subject with gender identity – all of which might well be independent on attitudes towards school science.

Subject preference studies typically list school subjects and ask students to rank them in order of importance (Jovanovic and King 1998; Lightbody and Durndell 1996b; Whitfield 1980). The main criticism of such studies is that a student might still have a positive attitude towards science yet rank science lowly as they are more positive about other subjects. Such scales only establish a relative ranking rather than an absolute measure.

A common criticism of all attitude scales derived from questionnaire surveys is that, while they are useful in identifying the nature of student attitudes, they have been of little help in understanding the generative mechanisms. This has led, more recently, to the growth of *qualitative methodological approaches*, three recent examples of which are studies undertaken by Britt Lindahl (2007), Terry Lyons (2006) and Jonathan Osborne and Sue Collins (2001). While such studies are subject to limited generalisability and, of necessity, have smaller samples and lack the ability to identify significant variables in a clearly defined manner, they can provide more insight into the origins of attitudes to school science than quantitative methods. For instance, it is difficult to envisage how the following student perceptions of the nature of school science and the disjuncture that exists with contemporary science could be elicited through survey methods:

> Roshni: The blast furnace, so when are you going to use a blast furnace? I mean, why do you need to know about it? You're not going to come across it ever. I mean look at the technology today, we've gone onto cloning. I mean it's a bit away off from the blast furnace now, so why do you need to know it? (Osborne and Collins 2001, p. 449)

What Is Known About Student Attitudes to Science?

Emerging from this body of work on attitudes towards science are some clearly defined features. First, students' attitudes towards school science typically decline from the first year of elementary school onwards (Murphy and Beggs 2003; Pell and Jarvis 2001). Studies conducted in secondary schools have identified a similar trend (Breakwell and Beardsell 1992; Simpson and Oliver 1985; Yager and Penick 1986).

In one sense, this is not surprising as attitudes towards school decline throughout adolescence (Eccles and Wigfield 1992; Epstein and McPartland 1976). The more fundamental question is how such attitudes to science decline relative to attitudes to other subjects. Richard Whitfield's (1980) analysis of 1971 Institute for Educational Assessment data showed that physics and chemistry were two of the least popular subjects once children reach the age of 14 years, and that these were distanced in pupils' minds from biology, a finding confirmed as still existing in a small study conducted by Neil Havard (1996). A similar picture of differential ranking between the sciences emerges from Osborne and Collins' (2001) study. Given the relative simplicity of Whitfield's instrument and its use of preference ranking, it is perhaps surprising that this kind of study has not been repeated on a larger scale. What such studies do, however, is to call into question whether the construct of 'attitude towards school science' is really a valid construct as students clearly have different attitudes towards the different sciences – though such a point is only true for high school students who have been taught courses that have more explicitly distinguished the sciences.

A study which has attracted considerable attention recently is the Norwegian-based ROSE study (Sjøberg and Schreiner 2005). Students were asked to respond on a 4-point Likert scale about whether they agree or disagree to statements of the kind 'I like school science better than other subjects'. Two major features emerged from these data and other responses: the decreasing interest in school science in more advanced, industrialised countries; and the more negative attitudes of girls. Whereas all of the samples were opportunistic and not randomly selected, such data have been greeted with some alarm in the developed world where there is a significant body of concern about the future supply of scientists (European Commission 2004; Lord Sainsbury of Turville 2007; National Academy of Sciences: Committee on Science Engineering and Public Policy 2005). However, another interpretation of these data is that, even in the worst-case scenario (Norway), 40% of boys and 22% of girls answered this question positively. On that basis, a question must be asked whether the concern has been exaggerated.

Similar findings emerge from an analysis of the 1999 data for the Third International Mathematics and Science Study (TIMSS) by Yasushi Ogura (2006). Ogura plotted students' achievement scores, measured by their knowledge of science concepts, against the mean of their responses to various items measuring their attitudes towards science. Again what stands out is that those countries whose students were the most successful, and which many other countries seek to emulate and which offer a very traditional science education with an emphasis on learning scientific knowledge, have students with the most negative attitudes. Such alienation is undoubtedly of concern to teachers, as their job satisfaction is likely to be strongly influenced by their pupils' affective responses to what is offered in science lessons. Moreover, recent evidence comparing the performance of Chinese and American students on tests of conceptual knowledge and scientific reasoning shows that, whereas those educated in China perform significantly better on tests of conceptual knowledge, they perform no better on tests of scientific reasoning (Bao et al. 2009). Thus, if the goal is to develop students' ability to think critically, an emphasis on content might have little effect.

Insights into student dissatisfaction with school science come from qualitative studies that have articulated the student voice (Lindahl 2007; Lyons 2006; Osborne and Collins 2001). Students complain that: school science lacks relevance; consists of too much repetition in that similar concepts appear in both the elementary, middle and high school curriculum; there is a lack of opportunity to discuss the science or it implications; and there is an overemphasis on copying as the standard form of writing. In addition, the curriculum appears to be dominated by a large body of content which must be learnt and reproduced for examinations – which is reinforced by the use of 'high stakes testing' as an accountability mechanism (Au 2007). Wayne Au's work – an extensive meta-analysis of all relevant studies undertaken in the field of assessment – led him to the conclusion that the consequence of such testing is a more fragmented curriculum and a pedagogy dominated by transmission – an approach which tends to lead to performance learning by students who are motivated by extrinsic rewards rather than by an inherent interest in the subject itself.

Detailed insights into why such an approach singularly fails to engage students comes from a study led by Mihaly Csikszenmihalyi and Barbara Schneider (2000) using the theoretical concept of 'flow' – the feeling generated by total engagement with an activity. They collected data at random from students eight times a day using a one-page, self-report form to identify the kinds of experience that are generative of 'flow'. Developing a composite measure of optimal learning experiences from data that included measures of challenge and skill, as well as concentration and enjoyment, they found that tests and quizzes, group work and individual work all produced above-average levels of 'flow', whereas listening to lectures and watching television or videos produced little 'flow'. Their conclusion was that classroom activities that facilitate flow experiences are those that are well structured and for which students are given adequate opportunities to demonstrate their skills and knowledge as autonomous individuals. One of the experiences that clearly generates the experience of 'flow' for most pupils is laboratory work (Csikszentmihalyi and Schneider 2000; Solomon 1980; Woolnough 1994), but the failure of school science to generate sufficient experiences of this nature remains a matter of concern.

Such findings support the view that school science education is unappealing when it is dominated by short-term goals, presented through lectures with an emphasis on transmission, and lacks challenge. Other research suggests that what school science lacks for students is a sense of purpose – why does it matter, what are its major ideas, how do they relate to each other and why should these matter to students (Claxton 1991; Millar and Osborne 1998; Osborne 2008)?

Nevertheless, most studies report that students' attitudes towards the overall experience of their science course are predominantly positive. For instance, for a sample of 1,227 English students, 61% agreed or strongly agreed with the statement 'school science is interesting'. Such data are similar to those found in previous studies (Assessment of Performance Unit 1988; The Research Business 1994). Moreover, a recent study of public attitudes to science by the Research Councils UK (2008), based on a random sample of 2,137 individuals, found that a third of young people (aged 16–24 years) felt that their school science education had been better than other subjects and that 43% felt it had been about the same. Comparable figures for adults (aged 25 years or over) were, respectively, 17% and 48%. Likewise, the recent PISA studies of 8th grade students present a similar positive picture of US students, with 45% indicating that they would like to study science after high school (OECD 2007).

What Are the Major Factors Determining Student Engagement with Science?

Research has identified a number of variables which contribute towards student engagement in science. Three factors stand out as the major determinants of student interest in school science – gender, the quality of teaching and pre-adolescent experiences. Space only permits detailed consideration of these three but more information can be found in previously published reviews (Osborne et al. 2003; Schibeci 1984).

Paul Gardner comments that sex is probably the most significant variable related to pupils' attitude to science (Gardner 1975). This view is supported by Renato Schibeci's (1984) extensive review of the literature, and more recent meta-analyses of a range of research studies (Brotman and Moore 2008; Murphy and Whitelegg 2006; Weinburgh 1995) covering the literature between 1970 and 2005. All four publications summarise numerous research studies to show that boys have a consistently more positive attitude to school science than girls – a finding confirmed by the data emerging from the ROSE study (Sjøberg and Schreiner 2005) and more recent work (Haste 2004; Jones et al. 2000). However, it would be better to say that the real difference is in attitudes to the physical sciences and engineering (OECD 2006) and, despite a large number of interventions undertaken in the 1980s and 1990s to engage more young women with the study of science, Gail Jones et al. (2000) concluded 'that the future pipeline of scientists and engineers is likely to remain unchanged' (p. 190). Thus, this problem is both chronic and a matter of concern (Adamuti-Trache and Andres 2008). Despite 25 years of effort, little, if any, change has been achieved. This is a matter of concern because young women who choose to study science and mathematics in high school have an 'increased likelihood of attending a university and a much broader range of program options at the post-secondary level' (Adamuti-Trache and Andres 2008, p. 1577).

A useful review of nine explanatory hypotheses for women's lack of engagement with science is offered by Jacob Blickenstaff (2005) who argues strongly against the suggestion that there are innate genetic differences. Rather, examining the other hypotheses, he suggests that the problem is complex and not amenable to simplistic solutions. Currently, the most useful insights come from work that focuses on the context in which physics is presented. For instance, the ROSE questionnaire presents 108 topics about which students might like to learn and asks respondents to rate them from 'not at all interested' to 'very interested'. Between English boys and girls there were 80 statistically significant differences. The top five items for boys and girls are shown in Table 41.1.

Table 41.1 The five top-ranked items that boys would like to learn about in science and the top five for girls (Jenkins and Nelson 2005)

Boys	Girls
Explosive chemicals	Why we dream when we are sleeping and what the dreams might mean
How it feels to be weightless in space	Cancer – what we know and how we can treat it
How the atom bomb functions	How to perform first aid and use basic medical equipment
Biological and chemical weapons and what they do to the human body	How to exercise the body to keep fit and strong
Black holes, supernovae and other spectacular objects in outer space	Sexually transmitted diseases and how to be protected against them

Based on the stark contrasts in lists such as these, it has been argued that the content of interest to girls is significantly under-represented in the curriculum (Haussler and Hoffmann 2002). These data are also supported by other research which would suggest that girls would be interested in a physics curriculum which had more human-related content (Krogh and Thomsen 2005). Indeed, a recent survey by Helen Haste and colleagues (2008) of student attitudes based on a sample of 327 14–15-year-old boys and 256 girls looked at how their perceptions of science were related to their personal, social and ethical values. Dividing the sample into those orientated towards science by positive responses to questions about employment in science and an expressed interest in technology, a factor analysis of the data was conducted. Haste et al. found four factors which discriminated between boys and girls: 'trust in the benefits of science', 'science in my life', 'ethical scepticism' and 'facts and high-tech fixes'. For girls, regardless of their inclination towards science, the consideration of ethical factors was a large positive explanatory factor while it was a negative factor for boys. Likewise, the perceptions of how science was relevant to their lives were a large contributing factor for girls positively inclined towards science but not for any other groups. In short, both the context, purpose and implications matter for girls and any attempt to present a decontextualised, value-free notion of science is likely to reduce their engagement. Such data also strongly suggest that offering a homogeneous curriculum to all is a mistake – what interests girls is unlikely to interest boys and vice versa.

Quality of Teaching

Quality of teaching is a difficult construct to operationalise, let alone measure. Nevertheless, a considerable body of evidence now exists that identifies the quality of teaching as a major determinant of student engagement with and success in a school subject (e.g. Osborne et al. 2003; Rivkin et al. 2005; Wayne and Youngs 2003). The most recent systematic study was undertaken in two states in the USA by Linda Darling-Hammond (2007), who showed that the major factor correlating with the percentage of students scoring ‘below basic’ on the South Carolina state tests were the percentage of teachers with substandard teaching certificates and the percentage of teaching vacancies open for more than 9 weeks. In contrast, teachers having advanced degrees correlated negatively with the percentage of ‘below basic’ scores. Likewise, in the state of Massachusetts, the two factors correlating most highly with the number of students failing the State English language test were the percentage of teachers unlicensed in the field and the percentage of paraprofessionals not highly qualified. A major OECD commissioned international review of school systems (Barber and Mourshed 2007) found:

> The experience of these top school systems suggests that three things matter most: 1) getting the right people to become teachers, 2) developing them into effective instructors and, 3) ensuring that the system is able to deliver the best possible instructions for each child (p. 5)

On the basis of comparative data across educational systems on student outcomes, Barber and Mourshed argued that reform efforts are often ineffective in delivering student learning and engagement if they do not reach down into classroom instruction, where the real effects on learning take place.

Identifying the constitutive elements of what makes a good teacher of science has been the focus of several strands of research including a series of projects at the secondary level by Ken Tobin and Barry Fraser (Garnett and Tobin 1989; Tobin and Fraser 1990; Tobin et al. 1994) and at primary level by Russell Tytler and colleagues (Tytler 2003; Tytler et al. 2004). Clearly a necessary condition is good subject knowledge which provides a base level of confidence essential for providing high-quality feedback and scaffolding (Hattie and Timperley 2007). Robin Alexander (2005) argues powerfully for a pedagogy based more in a dialogic approach suggesting that, whereas ‘rote, recitation and expository teaching’ might provide teachers with a sense of security as they enable the teacher to remain firmly in control, they make it less likely that the classroom will become a theatre for dealing with awkward, contingent questions which deal with issues of evidence and reasons for belief – exactly the kind of interaction, which Leo Van Lier (1996) argues, is engaging. Robert Sparkes (1995) makes the salient point that there is no problem with the supply of teachers of physics in Scotland as good teachers generate engaged students who in turn become teachers. Hence a problem never arises.

Pre-adolescent Engagement with Science

Student interest in science at the age of 10 years has been shown to be high and with little gender differences in either interest (Murphy and Beggs 2005; Pell and Jarvis 2001) or aptitude (Haworth et al. 2008). However, recent research suggests that, by the age of 14 years, interest in pursuing further study of science has largely been formed for the majority of students. In a recent analysis of data collected for the US National Educational Longitudinal Study, Robert Tai et al. (2006) showed that, by the age of 14 years, students with expectations of science-related careers were 3.4 times more likely to earn a physical science and engineering degree than students without similar expectations. This effect was even more pronounced for those who demonstrated high ability in mathematics – 51% being likely to undertake a STEM-related degree. Indeed Tai et al.'s analysis shows that the average mathematics achiever at age 14 years with a science-related career aspiration has a greater chance of achieving a physical science/engineering degree than a high mathematics achiever with a non-science career aspiration (34% compared to 19%). Further evidence that children's life-world experiences prior to the age of 14 years are the major determinant of any decision to pursue the study of science comes from a survey by the Royal Society (2006) of 1,141 SET practitioners' reasons for pursuing scientific careers. Just over a quarter of respondents (28%) first started thinking about a career in STEM before the age of 11 years and a further third (35%) between the ages of 12 and 14 years. Similar evidence came from a study by Adam Maltese and Robert Tai (2008) based on analysis of interviews with 116 scientists and graduate students. They found that 65% of respondents claimed interest in pursuing science prior to middle school and a further 30% during middle and high school. An interesting gender difference arose in this study, with females more likely to ascribe interest related to school or family compared with males who tended to claim intrinsic or self-related interest in science. Likewise, a small-scale longitudinal study conducted by Britt Lindahl (2007) followed 70 Swedish students from grade 5 (age 12 years) to grade 9 (age 16 years) and revealed that their career aspirations and interest in science were largely formed by age 13 years. Lindahl concluded that engaging older children in science would become progressively harder. Similar data can also be found in the work of Bandura et al. (2001) on children's aspirations and career choices.

Such data demonstrate the importance of the formation of career aspirations of young adolescents long before the point at which many make the choice about subjects in which to specialise. These findings suggest that efforts to engage school students with science would be more productively expended by: understanding the formative influences on student career aspirations between the ages of 10 and 14 years; and attempting to foster and maximise the interest of this cohort of adolescents, particularly girls, in STEM-related careers.

Other Variables

The determinants of student choice of science as a subject, or Science, Technology, Engineering and Mathematics (STEM) subjects generally, are multiple and interacting. Nadya Fouad and colleagues (2007) used a questionnaire with 1,151 students at different stages of schooling to identify key supports and barriers. The instrument was based on social cognitive career theory that considers student interest and aspirations in terms of interactions between personal factors and learning experiences on self-efficacy and outcome expectations. Key barriers identified were perceptions of subject difficulty (related to self-efficacy) and the presence of test anxiety. The list of variables that were significant predictors of choice to take ongoing science subjects were *science interest* (which, as we have shown above, itself might represent a number of factors), self-evaluation of science ability, parental expectation and guidance, exposure to career guidance and having goals, and exposure to inspirational teachers. For middle and high school students, teacher support and teacher expectations of success were significant supports.

The question of the difficulty of subject seems to be more important for mathematics than science, and for physical sciences than biological sciences. Lyons (2006) studied attitudes to science and backgrounds to subject choice for high-performing year 10 students in Australia. He used a combination of questionnaire and interview data. From the interview data, he identified that students choosing physical science were those who had supportive family relationships, parents who recognised the value of formal education, and family members advocating or supporting an interest in science. These students had higher levels of self-efficacy, which he argued was important in their decision to take these subjects with a reputation for difficulty. Lyons explained these findings in terms of 'cultural and social capital' needed by students to select into STEM pathways.

Maria Adamuti-Trache and Lesley Andres (2008) drew upon Pierre Bourdieu's work in examining the level of influence that parents have in transmitting cultural values and practices to their children, and thus disposing them towards STEM fields of study. Students with university-educated parents were shown in this study to decide earlier about their career directions, and they were more likely to choose science subjects. Thus, it is reasonable to infer that the transmission of cultural capital restricts prematurely the pathways of students whose parents and family contexts do not facilitate, encourage, assist and fund academic pursuits in STEM. There is also evidence from this study that the job satisfaction of parents in STEM careers, particularly the mother, can have significant influence on children's career aspirations.

The influence of parents is not necessarily straightforward. The Australian Department of Education Science and Training's (DEST 2006) Youth Attitudes Survey found that students who chose science and technology subjects reported overall higher levels of parental influence upon their decision-making. Haeusler and Kay (1997) found that parental and teacher advice played a more prominent role in the selection of science subjects than for other school subjects, and there is some evidence (Watt 2005) that this influence is greater in the earlier years of schooling, compared to the later years when perceived natural talent and interest drives choice.

A recent UK study conducted by the National Foundation for Educational Research for the UK government (Blenkinsop et al. 2006) points to the work of Bandura and colleagues (2001) who perceive self-efficacy (the belief that one has the power to produce effects by one's actions) as having greater predictive power in occupational choice than other theories. Following an analysis of socio-cognitive data from 272 children, they concluded that self-efficacy emerged from the interaction between 'socioeconomic, familial, academic and self-referent influences [operating] in concert to shape young people's career trajectories' (Bandura in Blenkinsop et al. 2006, p. 4). Family socio-economic status, they argued, had only an indirect effect on young people's perceptions of their capabilities. Higher status parents had raised parental aspirations which, in turn, were passed on to their children both as expectations and belief in their own capabilities and academic aspirations.

Many studies have shown that students who persist in STEM are more likely to have higher socio-economic status (see Committee for the Review of Teaching and Teacher Education 2003; Helme and Lamb 2007; Lamb and Ball 1999; Thomson and De Bortoli 2008). However, there continue to be questions raised about the nature of the causal link operating and the usefulness of SES as an indicator of student participation in STEM subjects. We have seen in the studies above how social capital and child–parent relations are important, and these can link to SES. Robert Putnam (2001, 2004) found that community-based social capital was a better indicator of improved educational outcomes than socio-economic status. David Grissmer et al. (2000) argue that this occurs through 'peer effects, quality of communication and trust among families in communities, the safety of neighbourhoods, and the presence of community institutions that support achievement' (pp. 17–18). Further research into this issue is required.

A few studies have shown the interactions between these various factors – self-efficacy, perceived difficulty and usefulness, parental and teacher encouragement – at different stages in schooling. For instance, Maltese (2008) undertook a complex data analysis of a large US longitudinal data set involving information over the school and college years about family demographics and background, academic support and achievement test results in a variety of subjects. He found a complex flow into and out of STEM subjects governed by a variety of factors, namely, the importance of early perceived usefulness of STEM (as an indicator of future degrees in STEM), academic score as an important indicator of choice of subject, the perception of usefulness of science and mathematics (a positive indicator of persistence in these subjects). However, a teaching emphasis on lecturing and textbooks was a negative indicator of persistence in science.

Anna Cleaves (2005) conducted interviews with 72 high-achieving secondary students to explore the factors influencing their subject choices across time from year 9 to year 11. She used a grounded theory approach to separate student trajectories into five categories that represented different patterns of choice regarding persistence, or not, in STEM. In the study, she identified many of the negative attributions to school science that have been described in the literature, such as irrelevance and boredom and stereotypical views of scientists and their work. However, for some students, these negative experiences were not enough to deter them from a commitment to pursue further studies. Cleaves paints a picture of interested students choosing to continue in STEM study, despite negative experiences of school science, and gaining a deeper appreciation of what a science career might be like outside of the classroom. She argues that raising the profile of science and understanding of science-related work are important in encouraging students into science. She adopts an identity framework to interpret the self-perceptions of students, showing that students' perceptions of their ability, in conjunction with their life aspirations, drive the decision to opt into, or out of, STEM (see also Leonardi et al. 1998).

A particular question of interest has been how much students know about careers in science. For instance, Lindahl's (2007) longitudinal study of students and their aspirations revealed that, at the early ages when their career aspirations were being broadly set, students had very little idea about the variety of work to which a focus on science subjects might lead. This has been the broad finding of a number of studies (e.g. Blenkinsop et al. 2006; Stagg 2007). A survey conducted in the UK for the Engineering Council by the National Foundation for Educational Research using a questionnaire survey of a random sample of 1,011 students at age 14 (Engineering and Technology Board 2005) found very limited and stereotypical views of what engineers, technologists and scientists might do. Technology was seen as the province of 'designing things' and 'having new ideas', and was correspondingly popular as a potential career. In terms of information about careers, Sarah Blenkinsop et al. (2006) reported that 14–16 year olds believed that media portrayal of jobs and careers influenced their choices, but that direct information from someone who works in the job, or a school careers teacher, is more likely to have been influential. Contact with people working in the field has been found to be highly valued:

> People, their lives, and the work they do are the richest and most respected resource for learning about careers. Whilst a proportion of young people are attracted to science and technology for itself, many are interested first in the people (role models, etc.). (Stagg 2007, p. 4)

This was a finding echoed, particularly for girls, by Gayle Buck et al. (2008) who found that role models were people with whom they held a 'deep personal connection' and that it was essential to establish a personal connection with girls if they were to engage them with the work that scientists undertake.

Students identified subject teachers as the most useful source of career information, but UK research has revealed that teachers of science did not perceive themselves as a source of career information, regarding it as the responsibility of the careers teacher (Munro and Elsom 2000). Further, Peter Stagg (2007) found that teachers were not well informed about careers in science let alone careers outside science which permitted the study of science. This situation is not aided by the fact that most careers teachers come predominantly from non-science backgrounds. These findings suggest that there is a need to develop an effective policy approach to enable students to be more aware of career possibilities associated with science.

The final point that should be made here is that the basic premise of this concern – that not enough children are choosing to study science – is open to question. There is a growing body of evidence that the production of scientists is in fact healthy (e.g. Butz et al. 2003; Lynn and Salzman 2006; Teitelbaum 2007). Further, Christopher Hill (2007) has made a cogent argument that advanced societies will become 'post-scientific' over those that are less dependent on basic scientific research and more dependent on their ability to create new artefacts by drawing on a range of disciplinary knowledge.

Identity: Making Sense of Student Engagement with Science

To understand student responses to science, there has been recent and increasing interest in exploring the construct of identity. This has been fruitful both for exploring the complexity of student responses to the science curriculum, and for making sense of the response of coherent groups such as indigenous or gender groupings.

Glen Aikenhead (2005) argues that, for many students, especially indigenous students, coming to appreciate science requires an identity shift in which students come to consider themselves as science-friendly – that 'to learn science meaningfully is identity work' (p. 117). Similarly, he argues that the persistence of status quo versions of school science in the face of considerable critique relates to the strong discursive traditions subscribed to by teachers of science resulting from their enculturation during their own schooling and undergraduate studies. There is widespread concern in many countries about gaps in performance in science and other subjects between indigenous and non-indigenous students (e.g. Thomson and De Bortoli 2008). Aikenhead and Masakata Ogawa (2007) argue that school science tends to portray scientific ways of knowing as free from value and without context. This way of presenting school science, without multiple or contested views, tends to marginalise some students on the basis of their 'cultural self-identities' (Aikenhead and Ogawa 2007, p. 540). Aikenhead (2001, p. 338) argues elsewhere that only a small minority of students' 'worldviews resonate with the scientific worldview conveyed most frequently in school science. All other students experience the single-mindedness of school science as alienating, and this hinders their effective participation in school science'. A further problem is the need to represent a broader range of identity futures consonant with science work. Elizabeth McKinley (2005) identifies the difficulty experienced by Maori women scientists in managing inconsistent images of themselves – as women, as Maori and as scientists – and argues that competing legacies of science, knowledge and culture have built strong cultural stereotypes of Maori women, who in interviews describe being discriminated against, prejudged and overlooked in their scientific roles.

In a similar vein, Angela Johnson (2007) in the USA described barriers to science-interested minority females' continuing participation in STEM, such as lack of sensitivity to their difference, discouragement and a sense of alienation from school science. Johnson described how even a laudable activity such as asking students questions in lectures can advantage White male students who are more competitive and confident, and cause women to feel a loss of status and rob them of the opportunity to get to know their teachers on a personal level. In describing the experience of these women moving through undergraduate science, Johnson concludes:

> The first step in making science more encouraging … is for scientists to recognize that science has a culture, and that certain types of students may find it challenging to understand and navigate this culture … if scientists cannot let go of narrow, decontextualized presentations of science, they will have difficulty winning the respect of women who see their interest in science as inextricably united to their altruism. … Science has a rich history of service to humanity. When scientists present their lectures with no allusion to this context, it may not be because they are uninterested in it but only because such ties are so obvious to them already. (p. 819)

As we have shown, the evidence demonstrates that contemporary youth is not a homogeneous population. Young people in today's society see themselves as free to choose their address, religion, social group, politics, education, profession, sexuality, lifestyle and values (Beck and Beck-Gernsheim 2002). This is a considerable transformation from 40 years ago when choice was much more limited and expressed predominantly in terms of a young person's choice of profession. Adolescence is a particularly significant time when young people are first confronted by the need to construct their sense of self. As has been well documented, this situation creates a state of insecurity or moratorium (Head 1985). In some senses, this angst is not new, but the range of choices presented to contemporary youth is now much greater. The decision-making landscape is complex as young people negotiate as they select their school subjects, decide who they want to be, and address their aspirations for a fulfilling future. Furthermore, analysis is complicated by that fact that the barriers that hinder young people's decision-making are not always immediately apparent and will change over time, and in degree, as students grow and develop (Engineering and Technology Board 2005; Fouad et al. 2007; Walker 2007; Walker et al. 2006).

There is a significant body of research on the impact of identity on the education-related choices of young people (e.g. Archer et al. 2007; Boaler 1997; Francis 2000). Many of these choices – whether or not to continue, which subjects to continue with, who they will aspire to become – impact upon students' success or failure in fulfilling their aspirations. Nadya Fouad et al. (2005) found in the USA that while race does not have an impact on students' initial career aspirations, it does affect the barriers that students encounter as they take action to fulfil those aspirations. Such barriers might include expectations of teachers, peers or family, or lack of role models. From this, it is clear that 'choice' is a highly constrained concept in the context of education, and experienced as limited or expansive depending upon factors such as prior academic performance, student cultural capital or school location. In this respect, the work of Geoffrey Cohen et al. (2006), which has attempted to address such barriers, is extremely interesting. Cohen and his co-workers take a psychological approach and argue that what inhibits students' performance is what they term 'stereotypical threat' – the notion that individuals are members of a group of students who commonly are perceived to fail at science (e.g. African American or woman). By conducting a small intervention at the beginning of the year to address and challenge such notions, this group has been able to show significant improvements in the performance of underperforming minorities and women.

Identity is a construct that goes beyond concerns such as curricula, intrinsic interest or career intentions, and it frames aspirations and perceptions in terms of social relationships and self-processes instead (Lee 2002). In identity theory, the self (or selves) is bounded by social structures, and interactions shape the organisation and content of self. Analysing decisions to participate in and choose STEM courses and careers through an identity framework involves emphasising relationships with family, teachers, peers and others, and identifying the degree of synergy, or disjuncture, experienced by young people between their everyday lives and the educational pursuit of STEM (see Archer et al. 2007).

Two recent studies have contributed to our understanding of how youth respond to science, school science and environmental issues. Helen Haste (2004) conducted a survey of the values and beliefs that 704 11–21-year-old UK individuals held about science and technology. Her analysis identified four distinct groups of students: the 'green', who held ethical concerns about the environment, were sceptical about interfering with nature and were predominantly girls under 16 years;

the ‘techno-investors’ who were enthusiastic about technology and the beneficial effects of science, trusted scientists and the government, and were mostly male; the ‘science oriented’ who were interested in science, had faith in the general application of scientific ways of thinking, and were mostly male; and the ‘alienated from science’ who were bored with science and sceptical of its potential and who were predominantly female. Haste found that girls were not less interested in science or science careers than boys, but they focused on different things. Girls related more strongly to ‘green’ values associated with science (socially responsible and people-oriented aspects of science) than to the ‘space and hardware’ aspects which often dominate communication about science. She argued that the science curriculum needs to represent both these dimensions of science, as well as acknowledging the value aspects and ethical concerns surrounding science and its applications.

Camilla Schreiner (2006) administered a questionnaire which had been extensively validated to a sample of 1,204 Norwegian students drawn from 53 randomly selected schools consisting of equal numbers of boys and girls. From a cluster analysis of her sample, she identified five distinct student types, each of which had a different response to science and to their own aspirations with respect to science. As with the Haste study, the categories were highly gender specific and showed different patterns of response to a range of items relating to the perceived value of school science and science, as well as their future aspirations.

Schreiner interprets the low recruitment into STEM subjects in wealthy, modern societies in terms of changing values of youth in late modern societies. This analysis has a significant identity component. Schreiner and Svein Sjoberg (2007, p. 242), draw on three perspectives to make sense of the data:

1. Issues that are perceived as meaningful for young people in a country are dependent on the culture and the material conditions in the country.
2. An educational choice is an identity choice (see also Aikenhead et al. 2006).
3. Young people wish to be passionate about what they are doing and they wish to develop themselves and their abilities. They experience a range of possible and accessible options regarding their futures and, among the many alternatives, they choose the most interesting.

Examined from the first perspective, in early and late industrial countries where the major national project goals are progress, growth and building the country, scientists and engineers were seen as crucial to people’s lives and well-being. Likewise, in less-developed countries, young people have a rather heroic image of scientists. In late modern societies, however, these values have changed. In advanced societies with a diminishing industrial base, and where material needs are satiated compared to previous generations, the role and value of the scientist and technologist is diminished – especially when compared with the sports and media personalities that dominate the news media.

Schreiner and Sjoberg speculate that the main reason that young people, especially girls, are reluctant to participate in the physical sciences is because they often perceive the identities of engineers and physicists as incongruent with their own.

There is an abundant literature (Boaler 1997; Lightbody and Durndell 1996a; Mendick 2006; Walkerdine 1990) which argues that STEM subjects and careers have a masculine image that leads girls to reject identities connected with STEM. Schreiner and Sjoberg suggest that, if this perspective is correct (and that the identities of youth in late modern societies are connected with late modern values such as self-realisation, creativity and innovation, working with people and helping others, and making money), then attracting more students into STEM pathways will require transforming the images of STEM work to address the ideals of contemporary youth, and updating the content and practice of school STEM subjects to make these values more apparent.

This research into the interactions of identity with the nature of science and school science is important in making us aware of the complexity of the issue of response to school science, and that, if we are to engage students with science in school, thought needs to be given both to the complex and varied histories of students who attend our classes, as well as to the nature of the science curriculum. Because we cannot hope for a simple match, the strong message is that, if we are to enlist young people into science subjects or even science-friendly positions, then it will be necessary to present a richer vision of science and its value in school.

Enrichment Experiences in School Science

This work on identity highlights a direction that is being increasingly embraced by government reports into the status of school science: greater attention needs to be given to representing the practices of science and their social implications than traditionally has been the case. In a number of countries, this has led to projects designed to encourage more links between practising scientists and school science classrooms. Academies of science and engineering that are concerned with the decreasing number of students in these areas have supported initiatives that bring exemplars of contemporary practice into classrooms. From the perspective of the identity-based research described above, two measures are of value: the need to increase awareness of career options in the sciences; and the provision of a diversity of role models with which students can identify, in terms of the personal, human possibilities opened up by an education in the sciences.

Such schemes are often reported as very successful but, because the evidence is largely anecdotal and the schemes vary widely, there is limited scope to generalise about outcomes in these areas. In the USA, service learning, in which students spend time working in organisations on a voluntary basis as part of their studies, is well established and surveys of participants have been encouraging (Gutstein et al. 2006). The Australian School Innovation in Science, Technology and Mathematics (ASISTM) project, which involves partnerships between clusters of schools, scientific and industrial organisations, universities and government organisations, has facilitated the development of innovative curriculum experiences for students. A study of ASISTM exemplar projects (Tytler, Symington et al. 2008;

Table 41.2 Index of science-related activities for selected countries (OECD 2007)

	Mean		
Country	Whole sample	Boys	Girls
UK	–0.35	–0.25	–0.45
Germany	0.11	0.16	0.06
Finland	–0.16	–0.18	–0.15
USA	–0.09	0.04	–0.21

Tytler, Symington and Smith 2011) involved developing an innovation framework for interpreting these projects, pointing out that the practices and ideas developed were in alignment with the open pedagogies and focus on contemporary practice advocated in writing about schooling for students in their adolescent years. The Australian Scientists in Schools programme (www.scientistsinschools.edu.au) has over 500 scientists working as partners with teachers across the country and on a variety of projects. The model is one of equal partnership, aimed at motivating students and providing teachers with professional learning opportunities about the contemporary practice of science.

Some evidence for the value of such interventions comes from the recent PISA study of 8th grade students (OECD 2007), which asked them about the frequency with which they watched TV programs about science, read science magazines or newspapers, visited science websites, borrowed books on science topics, listened to radio programmes about advances in science, or attended a science club. From this they developed an index of science-related activities (−2.5 to +2.5). A sample of figures from the index is shown in Table 41.2. For nearly all the countries in the study, a positive unit of the index resulted in an enhanced science performance of around 20 points on the mean score of 500. Once again, girls had a lower level of engagement with such activities than boys. The question of interest is whether the weaker engagement of, for instance, UK students, is because of a lack of opportunity or lack of interest.

Enrichment activities for science are often designed at a local level at the instigation of enthusiasts or interested associations, and there is a lack of understanding about the variety of such initiatives or their relative effectiveness. There is considerable anecdotal and weak evidence that student learning and engagement in science are enhanced by participation in enrichment activities such as excursions, visits by science practitioners, travelling shows, competitions such as mathematics and science Olympiads or engineering design challenges, science clubs and extension activities. This is mainly because any one-off event is unlikely to lead to significant learning in and of itself. Secondly, the methodology for capturing such experiences and its outcomes still remains problematic (Osborne and Dillon 2007). Moreover, as John Cripps Clark (2006) found in a study of science-enthusiastic primary school teachers, elementary schools offer a considerable range of such activities in their curriculum, but these required dedicated efforts in the face of systemic factors operating against their inclusion. Mary Munro and David Elsoms' (2000) study of the choices made by UK students after the age of 16 years revealed that teachers regularly complained that the curriculum was so scripted and crowded that it discourages engagement in such activities, despite their perceived importance in providing a stimulating environment for engaging students in learning mathematics, science and technology.

The report from the Science Education in Europe: Critical Reflections forum (Osborne and Dillon 2008) makes the point that most of students' waking lives are spent out of school and that much of their science (a similar point could be made about mathematics) learning occurs largely in informal settings. There is a wealth of literature on learners' experience of informal settings and museums (see Falk et al. 2000; Leonie Rennie 2006), but there is a need for further research into the impact of these public science resources on student attitudes to and engagement with science.

Conclusion

In this chapter, we have attempted not only to present a body of evidence about what is known about the methods and outcomes of this field of attitudes and aspirations towards science, but also to develop an argument as to why the domain is significant and of enduring interest in the field of science education. In addition, our analysis has offered some insights into what issues remain to be studied. In its methodology, the field is at last learning from the errors of the past and looking increasingly to use instruments which have been tested and analysed for their validity and reliability. This has been supplemented by analyses of existing longitudinal data and some growth in studies of a qualitative nature. The challenge for the field is to develop better insights and, as a corollary, better theoretical models which account for student engagement (or the lack of it) with science. This is particularly pressing in the case of girls and certain ethnic and minority communities. Here, the research focus needs to be on identifying student aspirations, their formation and their diversity. The question to be explored, then, is what kind of formal educational experience in science might engage young people and assist a process of self-realisation – either by developing a better knowledge and understanding of the diversity of future careers offered by science or by developing an enhanced sense of self-esteem acquired through satisfactory learning experiences in science. Some of this could be achieved by paying more attention to educating students about the career opportunities offered by science. After all, students cannot aspire to that which they have never seen. A recent analysis of research in science education (Lee et al. 2009) of the three leading journals in the field would suggest that the topic still remains of interest, because the findings are of significant interest to policy makers and because, we contend, the answers to the questions raised by the study of attitudes and aspirations towards science are of central concern to improving any education in or about science.

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Chapter 42
Children's Attitudes to Primary Science

Karen Kerr and Colette Murphy

Attitudes toward science are often studied in an attempt to ascertain the possible reasons behind a decline in the number of students choosing to study science in secondary school and/or at tertiary level. However, there are several debated issues within the realm of attitudes toward science including: the diversity and interpretations of subcategories and the terms used to denote them, the link between attitudes and what children actually do (behavior), and what is meant by science. In this chapter we consider the relationship between the sub-categories and terms used in relation to attitudes toward science. Many of the subcategories and terms used in the literature delineate the emotional (such as a belief about science), cognitive (which includes motivation) and action-tendency (behavioral intent or manifested interest) components of attitudes. Through discussion of these three components we emphasize that when conducting attitudinal research, it is important to include questionnaire items/questions which actually consider action tendency.

This chapter also discusses some of the main concerns over measuring attitudes. The instruments that have traditionally been used to consider attitudes toward science are diverse in nature. However, with reference to primary children's attitudes, we demonstrate the importance of incorporating a mixture of quantitative and qualitative instruments. For example, Judith Ramsden (1998) suggested that a range of techniques must be used; we provide further details on the suggestions made by Cheryl Blalock et al. (2008).

We look to the future and consider new directions in attitudinal research work relating to children. Current research in this area by the authors involves the establishment of Children's Research Advisory Groups (CRAGs), following work carried out by Laura Lundy and Lesley McEvoy (2007, 2008). Children in these groups

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informed the processes, interpretations, and outcomes of the research. In our research, children informed the design of questionnaire instruments and interview schedules, as well as giving their interpretations on findings and what they considered to be the outcomes of the work (Murphy et al. 2010).

Relevant literature in relation to primary children's attitudes to science is discussed. The literature considered reflects two major aspects of school science: children's attitudes to the science topics taught, and their interest in and enjoyment of science lessons. The majority of studies discuss primary children's attitudes in relation to age and gender. Overall, this literature suggests that, at primary level, there is a decline in positive attitudes toward science with age. However, this decline is less apparent when children are involved in practical, investigative science activities (Murphy et al. 2004). With regard to interest in and enjoyment of science, a gender difference with respect to physical science is less obvious in more recent studies. A difference between findings with respect to gender in older studies compared with more recent studies emphasizes the importance of a cautious approach when discussing and comparing results from recent studies with those from older studies.

What Are Attitudes to Science?

Major recent reviews in this area, for example, by Ramsden (1998) and Simon (2000), begin by discussing confusion in terms. Even over 30 years ago this was an issue, as discussed by Gardner (1975). Indeed, Jonathon Osborne et al. (2003, p. 1053) began their recent and substantial review of the attitudes literature by suggesting that 30 years of research into attitudes toward science has been "bedeviled by a lack of clarity into the concept under investigation." The most pertinent distinction mentioned in almost every recent review relates to the broad categories outlined by Gardner (1975): scientific attitudes and attitudes toward science. In Table 42.1, we have outlined the references made to both types of attitudes as well as how authors have described aspects of scientific attitudes or attitudes to science.

The scientific attitudes outlined in Table 42.1 relate to the way scientists should think or the qualities they should have. For example, as attempts are made to increase the number of future scientists, students can be encouraged to question and look for answers to questions such as why the liver is the only organ than can grow back or the supposed impact of global warming on our weather. In doing so, teachers may encourage a questioning approach (Education Policies Commission 1962). Very often, scientific attitudes are defined within attitudinal studies to emphasize that they will not be studied because of their dissimilarity with the affective nature of attitudes toward science. Nevertheless, scientific attitudes have their place in science classrooms.

There are several debated issues within the realm of attitudes toward science including: the diversity and interpretations of subcategories and the terms used to denote them (as shown in Table 42.1 and Fig. 42.1), the link between attitudes and what children actually do (behavior), and what is meant by science.

Table 42.1 A summary of references to scientific attitudes and attitudes toward science

Attitude type	Description of the attitude	Reference
Scientific attitudes	Acceptance of scientific enquiry as a way of thought, Adoption of scientific attitudes	L.E. Klopfer (1971)
	"Styles of thinking which scientists are presumed to display" (e.g., open-mindedness, honesty, skepticism)	Gardner (1975, p. 2)
	"Students' approach to thinking about science"	Tom Haladyna and Joan Shaughnessy (1982, pp. 548–549)
	"Scientific attributes"	Thomas Koballa and Frank Crawley (1985, p. 223)
	Longing to know and understand: A questioning approach to all statements; a search for data and their meaning; a demand for verification; a respect for logic; and a consideration of premises and consequences	Education Policies Commission (1962, as cited in Osborne et al. 2002, p. 1054)
Attitudes toward science	React favorably or unfavorably to a definite object (e.g., science or scientists)	Gardner (1975)
	"General or enduring positive feeling about science"	Koballa and Crawley (1985, p. 223)
	"Attitudes or feelings toward science refer to a person's positive or negative response to the enterprise of science…whether a person likes or dislikes science"	Ronald Simpson, Thomas Koballa, Steve Oliver and Frank Crawley (1994, p. 213)
	Perception of the science teacher, Anxiety toward science, Value of science, Self-esteem at science, Motivation toward science, Enjoyment of science, Attitudes of peers and friends toward science, Attitudes of parents toward science, Nature of the classroom environment, Achievement in science, Fear of failure on course	Simon (2000, p. 105) and Osborne et al. (2002, p. 1054)

Subcategories and Terms

Ramsden (1998) suggested that the use of terms is a complex issue and that terms are often used interchangeably and their meanings often overlap. For example, the subcategories outlined in Fig. 42.1 include the terms feelings, perceptions, motivation, and enjoyment under the umbrella of attitudes. Ramsden (1998) included the terms interest, views, images, beliefs, and values. Based on her discussion of these terms, Ramsden (1998) concluded that attitudes are not unidimensional and include three components: cognitive, emotional, and action-tendency related in the following way:

> … attitudes…[are]…a state of readiness or predisposition to respond in a certain manner when confronted with certain stimuli … attitudes are reinforced by beliefs (the cognitive

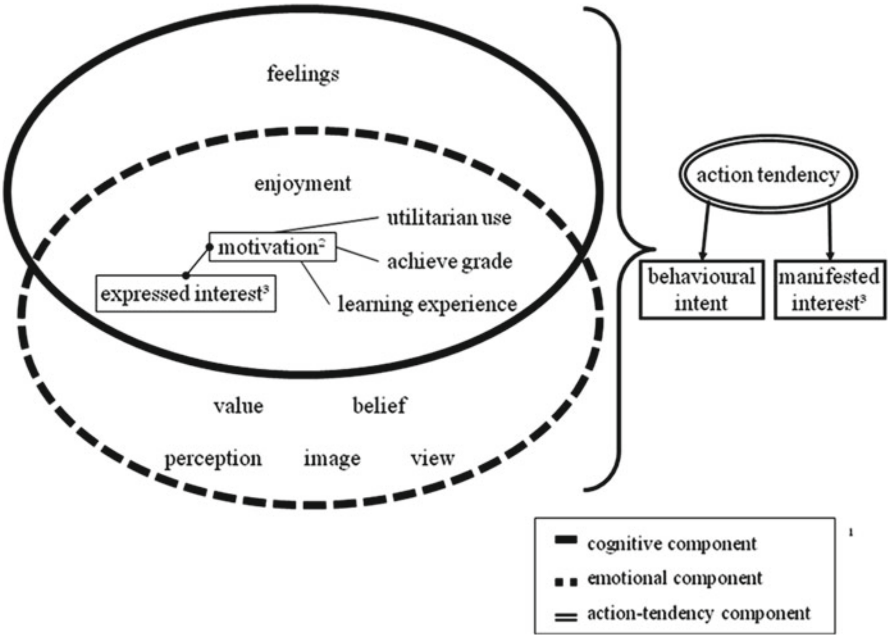

Fig. 42.1 A diagrammatical representation of the main relationships given by Ramsden (1998) and other researchers in relation to the terms used for attitudes

[1] The three attitudinal components outlined by Oppenheim (1992, p. 74)
[2] Strands of motivation outlined by Ramsden (1998, p. 128). The connection with interest was suggested by Gardner (1985)
[3] William Wall (1968) differentiated between expressed interest (like vs. dislike) and manifested interest (evidenced by hobbies)

> component), often attract string feelings (the emotional component) which may lead to particular behavioural intents (the action-tendency component). [Oppenheim 1992, p. 74, as cited in Ramsden (1998, p. 128)]

Figure 42.1 is based on this definition and we have diagrammatically represented some of the main relationships presented by Ramsden (1998) and other researchers in relation to the terms used for attitudes. The solid ring represents the cognitive components mentioned in some studies (e.g., Ramsden 1998). The dashed ring shows the words used to talk about and describe the emotional components of attitudes toward science, such as a perception of science that a child may have. The double-lined ring represents action tendency which can happen as a result of the cognitive and/or emotional components. For example, an action tendency can be children's involvement in science revision classes (manifested interest) because they are motivated by needing to achieve a higher grade for a university course (achieve grade – cognitive and emotional component).

The concept of "motivation" is also multidimensional. Gardner (1985) argued that motivation is related to declared interest. In other words, it is a measure of how willing children are to take part in certain actions in which they have expressed interest.

However, Ramsden (1998) pointed out that motivation can arise from other sources: utilitarian use (for a career), to achieve a grade or students can be motivated by a learning experience. Many secondary school children may be motivated by career choice or driven by the need to achieve a grade (in order to be accepted for a career). For example, students might take physics with the sole purpose of increasing their chances of acceptance to a medical course. However, the utilitarian and career components of motivation might not apply as strongly at primary level, except perhaps in countries where children's selection for secondary level education is based on high-stakes testing. The link with declared/expressed interest (Gardner 1985) should also be viewed with caution because children may like and be interested in an aspect of science that they have not specifically declared within a given study. For example, a child may be really interested in topics or different instructional procedures that have not been included in a research instrument.

Attitudes and Behavior

Children might express a preference for an element of science (expressed interest) or feeling about science (cognitive and emotional components), but they might not exhibit related behavior (Osborne et al. 2003). Children's behavior may be affected by other elements such as the attitudes of peers (Osborne et al. 2003). For example, children may not participate in a given science activity because they may not consider it to be "cool." The possibility that attitudes and behavior may be affected by other variables has led researchers to focus on behavior as opposed to whether or not children are interested in particular topics/activities (Osborne et al. 2003). Many researchers have reconsidered Icek Ajzen and Martin Fishbein's (1980) theory of reasoned action which differentiates between attitudes toward an object (science) and attitudes toward actions to be carried out on that object (activities, learning about topics). Ajzen and Fishbein (1980) claimed that finding out about attitudes toward actions is a better predictor of behavior than finding out about attitudes toward science itself. For example, children could be asked if they would like to learn more about given topics (an action) as opposed to being asked if they like it (an object). The behavior element is presented in Fig. 42.1 as the "action-tendency" component, how children intend to behave. Manifested interests (e.g., hobbies) are also considered part of the action-tendency component in Fig. 42.1. It is at this point that we will consider the issues around what is thought of as science in the context of attitudinal research.

What Is Science?

Charles Barman et al. (1997) considered fifth grade children's perceptions about scientists, science in school and science out of school. Barman et al. (1997) used the Draw-A-Scientist Test (DAST), originally developed by David Chambers (1983), and found that the majority of children drew white males who worked in some sort of laboratory. With regard to doing science in school, Barman et al. (1997) found that 56% of children drew themselves reading a science book or taking notes. Out-of-school science was characterized as an extension of school science by 60% of children (e.g., repeating school activities). These findings indicate that children think of science in different ways and reinforce the need for studies to differentiate between out-of-school science and in-school science (Osborne et al. 2003) with a focus on the latter (Ramsden 1998).

Ramsden (1998) also mentioned the issue of using science as an umbrella term to include biology, chemistry, physics, and possibly other areas. It is important to note that the impact of such a demarcation may not have the same effect on the expressed attitudes of primary school children compared with secondary school children. This is because many primary-aged children are unlikely to be aware of the different areas of science but a decline in positive attitudes toward physical science is well cited in literature relating to secondary school children (Bennett 2001; Haussler and Hoffman 2000). Nevertheless, a spread of topics/activities relating to the three major aspects (biological, chemical, and physical science) of science should be incorporated. Firstly, to address the possibility that children may already show signs of dislike toward a certain area of science at primary level. Secondly, including a range of topics from different science areas is representative of the current curricula.

For the most part, primary science is considered as school science because the majority of questions are related to in-school science. Ramsden (1998, p. 128) suggested we must collect data on a variety of aspects in order to look at "underlying trends and patterns," and claimed that such an approach is necessary because we can only deduce attitudes from words and actions because they "cannot be measured directly." Perhaps methodological issues surrounding attitudinal studies have arisen from a general assumption that attitudinal instruments actually measure attitudes, coupled with the confusion that comes with the diversity of instruments (Osborne et al. 2003) that claim to measure different aspects of science. The following section considers the much debated methodological issues relating to studies of children's attitudes to science.

Measuring Attitudes

Many of the issues surrounding the measurement of attitudes to science are analyzed, explored, and argued about in well-known reviews of the literature, spanning four decades – from a very early study by Gardner (1975), to later studies by Ramsden (1998) and Osborne et al. (2003), to a recent study by Blalock et al. (2008). Osborne et al. (2003) pointed out that the diversity of methods used in attitudes studies has led to the recognition of difficulties in measuring attitudes toward science, which is demonstrated in the extensive list of techniques and instruments (with examples) outlined by Gardner (1975) and Osborne et al. (2003). Both studies (Gardner 1975; Osborne 2003) mention the list of techniques and instruments outlined below. The examples given in both studies have been collapsed into this list:

- Summated rating scales – Likert scales, yes/no, agree/disagree, approve/disapprove (number of points on the scale vary)
- Semantic differential scales – use of bipolar adjectives (good/bad, interesting/dull) and participants are asked to indicate on a scale between these
- Interest inventories – participants tick what they find interesting from a given list
- Preference ranking – rank subjects in order of preference
- Enrollment data – number of students who take A-level sciences/proceed with aspects of science at third level
- Qualitative methodologies (Gardner referred to these as clinical and anthropological observations) – interviews, classroom observations

In addition to these, Gardner (1975) also specified the following instruments:

- Differential (Thurstone) scales – tick statements that best match beliefs; a mixture of positive and negative statements are included
- Rating scales – mainly external raters (teachers) asked to rate students along a numerical scale
- Projective techniques – word association, interpretation of drawings, sentence completion

We have given an overview of the methodologies used in studies which consider primary aged children in Table 42.2. In an attempt to group similar studies we have separated Table 42.2 into three sections. Comparative studies were those carried out in order to compare different samples. For example, one comparative study considered the attitudes of children from different countries (Murphy et al. 2006) and another compared children at different stages in an education system (Tymms 1997). Intervention studies considered aspects of children's attitudes before and after an intervention. Many of the studies in the *Other Studies* section in Table 42.2 considered different aspects of children's attitudes at a given time. It is evident from Table 42.2 that the majority of studies with primary children in recent years incorporated a mixture of questionnaire and interview-based questions.

In Fig. 42.2, we have graphically represented the methods used and variables considered in the primary studies outlined in Table 42.2. Counting the actual instruments/techniques/methods (Fig. 42.2) used to consider primary children's attitudes in well-cited studies showed that not all of the instruments outlined above by Gardner (1975) and Osborne et al. (2003) have been considered appropriate nor are regularly used with children of this age.

Traditionally, the majority of studies which consider primary school children's attitudes to science incorporate the use of Likert scales, open questions/interviews, subject preference, and semantic differential scales (Fig. 42.2). Ramsden (1998) suggested that interview methods must be included as a means of cross-checking written and verbal responses. Osborne et al. (2003, p. 1059) also suggested that open questions give more "insight into the origins of attitudes to school science." Karen Kerr (2008) also pointed out that children can talk about science

Table 42.2 A list of studies which consider primary children's attitudes to science

Study	Countries	Age band	Sample size	Aspects of attitudes	Methodology	Variables
Comparative studies						
Tymms (1997)	UK	10–11	5,000, 1,740	Self-concept in science (5,000 children)	5-point Likert scale	Overall sample school
				Achievement in science (1,740 children)	Multiple-choice test	
Catherine Woodward and Nicholas Woodward (1998a)	Wales	10–11	120 pupils in 3 years	Ranking of science Preferred and least preferred topics	Preference ranking	Gender
Chris Dawson (2000)	Australia	12–13	1980: 753 1997: 203	Topic preference Activity preference	Likert scale	Gender Sample years
Murphy and Beggs (2001)	Northern Ireland, England	8–11	979 (N.I.) 653 (Eng)	Topics: Enjoyment, importance, perceived ability Like best/not like/hardest thing	Semantic differential Likert scale Open questions	Age Gender Countries
Murphy et al. (2006) and Murphy and Beggs (2003)	Northern Ireland, Oman	8–11	979 (N.I.)	Topics: Enjoyment, importance, perceived ability	Semantic differential	Age, gender, ability
			944 (Oman)	Science in/out of/later in school	Likert scale Open Questions	Overall sample countries
Intervention studies						
Tina Jarvis and Tony Pell (2002)	England	10–11	655	Science enthusiasm and social context Space and getting the job done	Likert scales	Gender, age overall sample intervention
Murphy et al. (2004)	Northern Ireland	8–11	1,286	Topics: Enjoyment, importance, perceived ability	Semantic differential	Gender, age, overall sample intervention

				Something you remember from lessons	Likert scale	
					Open questions	
Jarvis and Pell (2005)	England	10–11	300	See factors outlined above (2002)	Likert scale	Overall sample intervention
				Information on attention, activities, independence, conversations	Observation of the visit	
				Recall, likes/dislikes, role, what they learned, become an astronaut?	Open questions	
Jenny Mant, Helen Wilson, and David Coates (2007)	England	10–11	Not specified	Achievement in national assessment test: % of level 5	% achieving level 5	Overall sample intervention
				Perceptions of the lessons	Focus groups	
				Perceptions of the lessons Perceptions of the impact of the lessons on their learning		
Other studies						
R. A. Hadden and A. H. Johnstone (1982)	Scotland	10–12	1,000+	Attitudes to studying science	Semantic differential with Likert	Overall sample
				Early perceptions of science	scale, structured discussions, free response	
M. B. Ormerod and Charles Wood (1983)	England	10–11	330	Attitudes to space and nature study	Likert scale, sentence completion	Gender, compare methods
				General attitudes	Projective tests	
Margaret Collins (1993)	England	5–6	35	Beliefs and boys'/girls' preferences, their science and scientists' work	Choose from a list	Gender

(continued)

Table 42.2 (continued)

Study	Countries	Age band	Sample size	Aspects of attitudes	Methodology	Variables
				Preferences for science work	Drawings with speech bubbles	Overall sample
				Activity preferences – boys and girls	Make a chart	
Barman et al. (1997)	USA	10–11	117	Perceptions: Scientists and in-school science	Drawings with explanations	Overall sample
				Using science out of school	Open questions	
Lynn Newton and Douglas Newton (1998)	England	4–12	1,000	Perceptions of scientists and science	Chamber's Draw-A-Scientist Test	Age, gender
Woodward and Woodward (1998b)	Wales	10–11	120 in 1991, 1993 & 1995	Subject preferences and prospective preferences. Subjects in which high	Select one subject Likert scale	Overall sample Gender
Thomas Andre et al. (1999)	USA	5–12	337	Self-competence Subject liking Gender and jobs	Likert scales	Age, gender
John Johnston et al. (1999)	Northern Ireland	10–11	1571	Learning disposition Enjoyment of science, parental influence, perceived difficulty, science as a boys' subject	Classroom observations	Gender
				Self-esteem and locus of control orientation Experiences of learning science and gender	5-point scale Open-ended statements 4-point Likert scale "yes" or "no" focus groups	School sector School size Class size
Andrew Pollard and Patricia Triggs (2000)	UK	5–11	54 in each year group	Attitudes to the curriculum	Most-liked and least-liked subjects	Age, gender Overall sample

Elizabeth Jurd (2001)	England	9–11	535	Activities, econdary school, Science at home, Usefulness	Likert scales Focus-group Interviews	Gender Overall sample
Tony Pell and Tina Jarvis (2001)	England	5–11	978	Independent investigator, Difficult subject, Enthusiasm, Social context	Likert scale	Age, gender Overall sample
Murphy and Beggs (2002)	Northern Ireland	8–11	979	Topics. Enjoyment, Importance, Perceived ability Enjoy/do not enjoy Hard and easy science	Semantic differential Likert scale Open questions	Age, gender
Christine Chin and G Kayalvizhi (2005)	Singapore	10–11	39	How I feel about doing investigations	Likert scale	Overall sample
				Investigation reflections	Open questions Planning sheets	Ability, gender

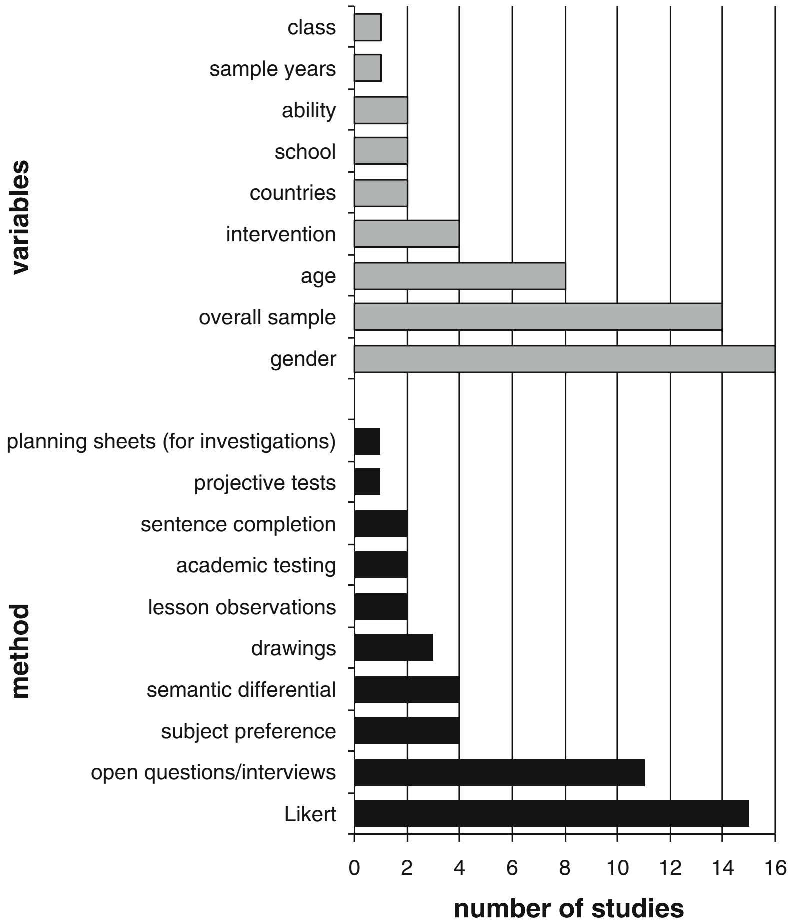

Fig. 42.2 Bar graphs to show the methods used in well-cited primary science studies and the variables considered

in unexpected ways when they are given the opportunity to talk about any aspect of science using a variety of methods (drawing, writing or talking). For example, children may dislike activities that adults assume they would enjoy, such as painting and playing with sand and water.

Only two primary studies compared children according to their academic ability (Fig. 42.2). Most studies which consider children's ability tend to incorporate secondary/university level pupils. This is perhaps due to the fact that students' performance at secondary/university levels is measured and can have an impact on their later lives/career decisions and motivation to achieve (Fig. 42.1).

With regard to variables, the majority of studies report their findings in relation to gender, overall sample, and age (Table 42.2). Traditionally, there has been an emphasis on the impact of gender on children's attitudes toward science. Perhaps the main reason for an emphasis on gender lies in the well-documented finding that "sex is probably the most significant variable related to attitudes to science" (Gardner 1975, p. 32). This view was generally supported by Milton Ormerod and Derek Duckworth (1975) and in Renato Schibeci's (1984) extensive review of literature. In their meta-analyses of literature, Becker (1989) and Molly Weinburgh (1995) also concurred with the view that gender has a large effect on attitudes to science in comparison with other variables. Nevertheless, Schibeci (1984) highlighted other primary level studies in which little or no gender effect was recorded: for example, studies conducted by Ayers and Price (1975) and Mohamed Selim and Robert Shrigley (1983). Haladyna and Shaughnessy (1982) carried out a large meta-analytic study of quantitative instruments and concluded that the difference between boys and girls was consistently small and varied between studies and grade levels. Gardner (1975, p. 29) argued that "teacher and pupil variables may exert more powerful effects upon attitudes than curricula and instructional materials." Although these studies are dated, the traditional emphasis on gender has continued in more recent attitudinal studies. Twelve of the 22 primary studies outlined in Table 42.2 have been conducted on or after the year 2000. Of these 12 studies, 10 have considered the impact of gender on children's attitudes toward science. All of the studies which considered gender reported that there were gender effects and in the majority of studies these effects were significant (e.g., Dawson 2000; Murphy and Beggs 2001). An earlier emphasis on gender as a significant variable (Gardner 1975) coupled with significant results since, has also contributed to the consideration of gender in attitudinal studies.

The final column in Table 42.2 demonstrates that in many primary studies there are only a few variables reported. It is also clear from Table 42.2 that the number and age of participants vary greatly. Not only has there been a well-documented focus on secondary school attitudes to science but many of the primary school studies that have been carried out (17 out of 22) focus on children in upper primary school. In Fig. 42.3, we have graphically represented the studies outlined in Table 42.2 in terms of the age and number of students. For example, only one study included children in every year of primary school with a sample size greater than 1,000 (Fig. 42.3).

The importance of a large sample size when carrying out a quantitative study cannot be underestimated. Many research texts suggest appropriate sample sizes for quantitative/questionnaire-based studies. Louis Cohen et al. (2000) suggested that research involving questionnaires should have no fewer than 100 cases in each major subgroup and 20–50 in each minor subgroup. Although not all of the primary studies shown in Fig. 42.3 were quantitative, it is interesting to note that 12 out of 22 studies had more than 500 participants. The largest and most extensive studies on specific aspects of children's attitudes to school science were carried out by Murphy and Beggs (2003, 2004) and Pell and Jarvis (2001). Of these, Pell and Jarvis (2001, p. 859) also advocated the importance of including younger children's attitudes as they found that "quite young pupils can provide worthwhile indicators of how they view science." As a result of including young children in every age group, as opposed to selected age groups, Pell and Jarvis (2001) graphically presented a year-on-year deterioration.

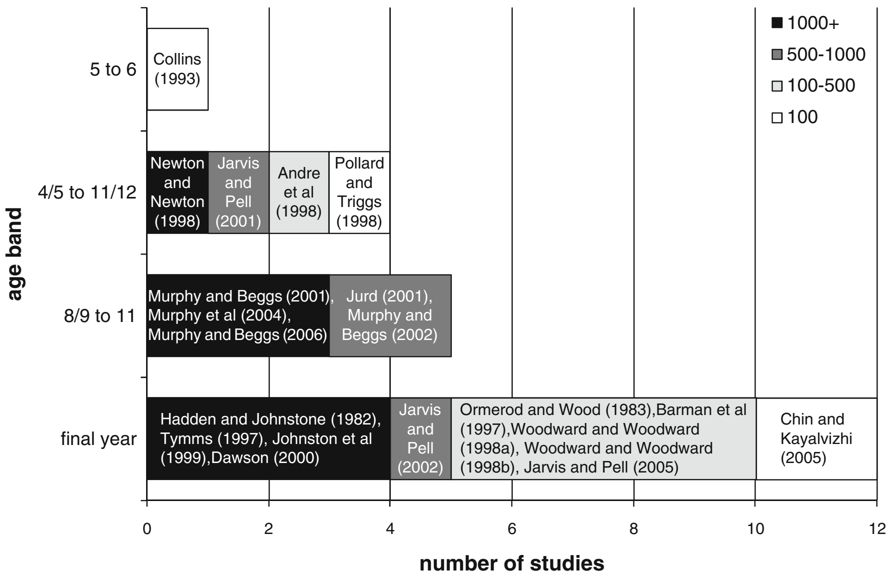

Fig. 42.3 A bar graph showing the number and age of participants involved in primary science attitude studies. The reference for each study has also been included

As well as a deterioration with age, Pell and Jarvis (2001, p. 860) pointed out that their other findings (e.g., in relation to gender) were in line with those of other studies, suggesting that "the instrument has value over a wide population."

Suggestions made by reviewers for improving attitudinal work offer an efficient summary of the issues raised with regard to measuring attitudes. Some of the main suggestions for conducting reliable and valid studies have been outlined succinctly by Ramsden (1998). A recent review of science attitude instruments with a focus on validity has been published by Blalock et al. (2008) who used a process of database searching and reference identification of peer-reviewed articles. Although Blalock et al. (2008) acknowledge that they only considered published, psychometric data they do outline tangible and important suggestions for conducting reliable studies. Their suggestions are based on the premise that it is better to refine, improve upon, and reuse the most promising instruments that are already in existence and carry out additional procedures (Blalock 2008). We have listed the suggestions outlined by Ramsden (1998) and Blalock (2008) in Table 42.3.

We would argue, however, that there could be another crucial element to attitudinal research with children which has, to date, been overlooked: the assumption of common understanding between the researcher and the researched, especially when the latter comprises children. To this end, our current work involves the establishment of children's research advisory groups (CRAGs) to inform all aspects of the research process (Murphy et al. 2010). The methodology was designed to ensure that the research process was compliant with international children's rights standards on

Table 42.3 An outline of the suggestions made in previous literature reviews to address reliability and validity in attitudinal research

Author(s)	Suggestion
Ramsden (1998)	Because issues of reliability and validity must be addressed, a range of techniques must be used.
	Interviews are highly desirable to validate instruments and provide the means for cross-checking with written and verbal responses.
	Collection should be repeated a few weeks later (because attitudes are unstable and changeable).
	Checks with both pupils and teachers would also aid validation.
Blalock et al. (2008)	Be more aware of the strengths and weaknesses of an instrument
	Reliability and validity evidence should be collected and reported.
	Compare with previous results to estimate generalizability
	Collect more data
	Deal with missing data and potential response bias
	Submit data to dimensionality analysis (e.g., explanatory and confirmatory factor analysis). As a result of such analysis, if no items or subscales form sensible structures for capturing science attitudes, that area would need to be reexamined.
	In agreement with Osborne et al. (2002), there must be a clear distinction between out-of-school science and in-school science because the latter is a better predictor of behavior.

children's participation (Laura Lundy 2007). The project's Children's Research Advisory Committee (CRAG) were be involved actively in the design and delivery of an online survey and in the analysis and dissemination of the results. The survey facilitated participating children not only in expressing their views but also in forming views through reading and analysis of a range of perspectives (Murphy et al. 2010).

Attitudes to Science

Ramsden (1998, p. 128) argued that attitudes cannot be "measured directly" but "inferred from words and actions," because attitudes are abstract concepts. Indeed, attitudes are not concrete, for example, because they can change or be changed. If children become involved with an activity that excites and enthuses them (such as growing their own vegetables), it may well have an impact on their attitude toward a topic (plants) on a given day or during a given lesson. However, this may be short-lived and they may feel differently if the next lesson focuses on an aspect that they do not like. Ramsden (1998) went further to suggest that any attempt at measurement must consider different aspects of attitudes and that we must look for underlying trends and patterns. However, the issues that ensue as a result of the diversity of attitudinal instruments, variables considered, and number and age of participants (Osborne et al. 2003) are intensified by confusion over the actual aspect of attitudes

- out of school science/social context
- perceived ability/difficulty

referred to in 6 studies

- topics
- perceptions of in-school science

referred to in 5 studies

- enjoyment
- activities
- experiences of learning science
- studying science later in school
- subject level preferences
- importance/usefulness

referred to in 4 studies

Fig. 42.4 The most common attitudinal aspects referred to in studies of primary science

under consideration (e.g., science content, science delivery, school science vs. societal science). Very often, the aspect under consideration is not defined or the title given to a factor is confusing. Analysis of Table 42.2 brought to light 29 named aspects that are considered within 22 primary studies. The most common aspects referred to are shown in Fig. 42.4.

The aspects are listed here using the exact wording from the primary studies mentioned in Table 42.2. The crossover between these aspects is obvious and emphasizes the need for specificity when comparing studies and their findings. For example, "enjoyment" is often referred to with respect to the "activities" children take part in and their "perceptions of in-school science" might well be what they think about the "topics" they cover in school. Perhaps the most effective way to study attitudes to science is to consider (and clearly outline) as many aspects as possible and thoroughly consider underlying patterns and trends (Ramsden 1998). The following sections will briefly outline two of the main aspects mentioned in the literature: attitudes to science topics, and interest in and enjoyment of school science. We selected these two areas because they are mentioned most frequently in the (primary science) literature and will therefore offer the greatest opportunity for other researchers to compare their own work in this area.

Children's Attitudes to Science Topics

The majority of studies which consider primary children's attitudes to science topics discuss their data with respect to age and gender. Andre et al. (1999) compared children's attitudes toward science with their attitudes toward other subjects and reported that older children (9–11 year old) were significantly more positive than younger children (5–8 year old) about life science and physical science. However, many studies relating to science topics at primary level document a decline in positive attitudes toward science content (topics). With specific reference to Northern Ireland, Murphy and Beggs (2002) reported that all 16 topics in their study (a mixture of biological, chemical, and physical) were liked more by 8/9 year olds than 10/11 year olds. In fact, 10/11 year olds were significantly less positive than 8/9 year olds about 12 topics: healthy living, animals, plants, life cycles, materials, water cycle, environment, recycling, forces, energy, sound, and light (Murphy and Beggs 2002). Murphy and her colleagues also conducted comparative studies with their Northern Irish sample and children in England (Murphy and Beggs 2001) and Oman (Murphy et al. 2006). The topics under consideration were part of the primary science curriculum in all three countries. Older children in England were also significantly less positive about eight topics when compared with their 8/9-year-old counterparts (Murphy and Beggs 2001). Overall, children in England were the least positive (Murphy and Beggs 2001). However, in Oman, older children were more positive about nine topics (Murphy et al. 2006). It would, therefore, appear that the decline in positive attitudes with age toward primary science topics is more obvious in England and Northern Ireland. This trend is concerning, given that the attitudes of students in England were compared with another country in the UK (Northern Ireland) and another country outside of the UK, on another continent (Oman). Murphy and Beggs (2001) suggested that the differences between the attitudes of children in Northern Ireland and England could be attributed, at least in part, to the assessment systems. At the time, in England and Northern Ireland, children were tested during the final year of primary school. Although children were tested in science in both countries, in England the assessment was more extensive: children had to complete more lengthy tests, mostly involving factual recall, and consequently, were involved a lot more repetitive revision compared with children in Northern Ireland. In Oman, on the other hand, there were no high-stakes testing in the final year of primary school, which could be a factor contributing to the smaller decline in positive attitudes to science in primary school as children get older.

It would appear that attitudes toward science topics decline significantly with age in Northern Ireland. However, Murphy et al. (2004) found that the decline was less significant when children were involved in more experimental science. Murphy et al. (2004) compared the attitudes of children who were involved with more experimental science activities (through lessons where their teachers cotaught with science-specialist student teachers) and those who were not. Younger children who were not involved in the intervention were significantly more positive about 12 topics when compared with older children. However, younger children who were involved in the intervention were significantly more positive about just three topics (Murphy et al. 2004). This is an important finding with respect to children's attitudes to science content (topics) and how they can be affected by how science is taught. Murphy et al. (2004) also found that there were fewer gender differences between boys and girls who were involved in the intervention. They speculated that in addition to the focus on investigative science, the fact that more than 90% of the specialist-science student teachers were female could have had some effect on improving female children's attitudes to the physical science topics.

Woodward and Woodward (1998a) considered 10/11-year-old children's preferred science topics and discussed their results with respect to gender. They found that the same topics were liked the most by boys and girls (space and planets, animals and plants). Interestingly, the topics with less appeal were also the same for boys and girls (magnets, weather, and sound). However, Woodward and Woodward (1998a) found that girls showed a higher preference for some topics (keeping healthy) when compared with boys and a lower preference for other topics (electricity). Murphy and Beggs (2002) also found that girls were significantly more positive about the topic "healthy living" and boys were significantly more positive about electricity. Although boys and girls might have a stronger preference for certain science topics, the issue of whether girls or boys are more positive overall is contested. Numerous studies report that, overall, girls are more positive about science topics. For example, Murphy and Beggs (2003) and Kerr (2008) all reported that girls were more positive about science topics. On the other hand, Dawson (2000) compared the attitudes of boys and girls in 1980 and 1997 and found that the overall mean (for topics) was higher for boys than girls. However, closer inspection of Dawson's findings reveals a positive shift in the spread of girls' positive attitudes toward science topics between the two sample years. In 1997, girls liked more physical science topics than in 1980 (Dawson 2000). In 1983, Ormerod and Wood also concluded that girls liked nature study more than boys, who preferred physical science. It would appear that all studies have attempted to bring to light subtle differences in the actual topics preferred by boys and girls (keeping healthy, electricity). Therefore, in order to draw comparisons with other research relating to gender and topics, specific findings toward individual topics was discussed. There is a difference between results from more recent samples (e.g., Dawson 1997; Murphy and Beggs 2003) and results from samples in the 1980s (Dawson 1980; Ormerod and Wood 1983). Namely, a gender difference with respect to physical science is less obvious. Therefore, this emphasizes the importance of a cautious approach when discussing and comparing results from current studies with those from older studies.

Children's Interest in and Enjoyment of Primary Science

The largest and most extensive studies which included specific reference to children's attitudes to primary science (lessons) were carried out by Murphy and Beggs (2003, 2004, 2006) and Pell and Jarvis (2001). All of these studies call attention to a decline in positive attitudes with age. Pell and Jarvis (2001, p. 859) considered the "science enthusiasm" of children aged 5–11 and showed "graphically the year on year deterioration." Murphy and Beggs (2003) found strong evidence of a significant decline in enjoyment of science between children aged 8/9 and 10/11. In fact, the 8/9-year-old children were significantly more positive about four out of six items related to enjoyment of science: science lessons are fun, I look forward to science lessons, solving science problems is enjoyable, and doing experiments is fun.

It is interesting to note that significantly more 10/11-year-old students thought they do too much writing in science (Murphy and Beggs 2003).

Discussion and comparison of practical, investigative science as opposed to traditional teaching methods (e.g., writing) is often discussed in relation to children's interest in and enjoyment of science. In fact, Murphy and Beggs (2003) also asked children open questions about what they liked and did not like in science. They found that the most common response to what they liked was "experiments," regardless of age, gender, or ability, while "writing" was a typical response in relation to what children did not like. Findings related to children's positive views about practical, investigative, active learning aspects of science are reiterated in numerous other studies. In Australia, Dawson (2000) compared boys and girls activity preferences in 1980 and 1997. Dawson (2000) found that boys and girls in both samples preferred creative and especially active learning activities as opposed to copying and informing. The children in Dawson's (2000) study were children in their last year of primary school. Collins (1993) considered infant school boys' and girls' preferences for science work and obtained similar results. Collins asked 35 children aged 5/6 years old to make a chart of their preferred science work. Boys and girls drew active learning activities such as drawing in science/making models (13 boys, 16 girls), and checking up/finding out more (10 boys, 7 girls).

Several studies have considered children's interest in and enjoyment of science before and after interventions which focus on investigative, practical elements of science. Mant et al. (2007) looked at the effect of increasing conceptual challenge in primary science lessons through use of discussion, experiments, and investigations and encouraging children to think for themselves. They then conducted 16 focus group interviews in the intervention schools. In every interview, children talked about how the lessons were better. Children said this was because there were more experiments and investigations and in 11 interviews children said it was because they spent less time writing. Murphy et al. (2004) compared the attitudes of children who were involved in more practical and investigative science (though the use of coteaching) with children who were not involved in the project. They present more compelling evidence for the effect of practical and investigative work given that children's enjoyment of science was influenced in the longer term. Unlike many studies which consider the effect of an intervention, attitudinal data were not collected until 6 months after the project. Murphy et al. (2004) found that children who were involved in the project were significantly more positive in response to the items: science lessons are fun, solving science problems is enjoyable (at $p < 0.01$), and I look forward to science lessons (at $p < 0.05$). Even though children were completing their questionnaire 6 months after the intervention, many of them talked about their enjoyment of science during the project in the open-response questions (Murphy et al. 2004). The studies by Mant et al. (2007) and Murphy et al. (2004) reported a positive effect on children's learning through use of practical work. Mant et al. (2007) reported that children themselves had a clear sense of doing helping learning. Murphy et al. (2004) stated that children could remember specific aspects of their learning in the open-response section of the questionnaire (which was carried out 6 months after the project). Teachers also talked about children's learning in their research journals (Murphy et al. 2004). It would appear that the message from boys and girls of all ages is a resounding thumbs-up for practical, investigative science.

Conclusion

Apart from the fact that the majority of studies have traditionally focused on older primary children and secondary school children, many issues are brought to the fore when literature about (primary) children's attitudes is considered and debated. These include the importance of clear and succinct delineation of and reference to exactly what is being measured, how it is measured, who is involved, and to what extent reliability and validity are addressed. These issues must be addressed given the huge diversity in attitudinal studies that have already been conducted.

Kerr (2008) also pointed out that young children can voice their likes, dislikes, and concerns from a very young age, and that children often talk about science in unexpected ways. When children are given the opportunity to talk about any aspect of science using a variety of methods (drawing, writing, talking), a wealth of different viewpoints become obvious. For example, although girls appeared more positive about school in the questionnaire items – they more frequently mentioned a dislike of writing in science in their open responses when compared with their male counterparts (Kerr 2008). In other words, it is imperative that we give children the opportunity to express their perspectives of science in a variety of different ways, including those which are more amenable to them.

New directions in attitudinal studies with children are focusing on the importance of including children's input, as an expert group, at each stage of the research process. Recent work carried out by Lundy and McEvoy (2008) has demonstrated very effective methods for researching children's perspectives. They pointed out that the involvement of children was a particular strength during the analysis phase because

> …it provided a children's perspective on other children's views which at times countered an adult interpretation of the views and as such led to a more nuanced understanding of the findings. (p. 33)

The authors of this chapter worked with Lundy and McEvoy to implement such techniques into attitudinal research in primary science (Murphy et al. 2010). We end with a personal communication from Laura Lundy (2008) from work she carried out with children's research advisory groups (CRAGs) which focused on assessment in primary school. The CRAG was asked to rank different feedback comments from teachers in relation to how each reflected the level of the work. The CRAG ranked feedback such as "brilliant" and "fantastic" quite low down on their list. In the ensuing discussion, the children implied that teachers frequently used such terms on work that the children said was not their best and, sometimes, not very good. The term they ranked top was "very good"!

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Chapter 43
Developing Measurement Instruments for Science Education Research

Xiufeng Liu

Standardized measurement instruments (SMIs) refer to tools that produce valid and reliable quantitative measures about a construct. Development of SMIs in science education has been an active field of research for the past five decades (Doran et al. 1994; Tamir 1998), which is particularly true for large-scale studies in science education (Britton and Schneider 2007). SMIs have been receiving increasing attention over the past decade for a number of reasons. First, there is a growing worldwide trend toward standards-based science education in which standardized testing is used for accountability. Second, there is a growing realization of limitations of qualitative research approaches and a call for randomized experimentation that incorporates standardized measurements (National Research Council [NRC] 2002). Third, the continuing interest in identifying student alternative conceptions has created a demand for more efficient and large-scale survey of student alternative conceptions. Today, SMIs are playing a vital role in various science education research programs and will continue to do so in the future.

This chapter reviews the development of SMIs in refereed science education publications by excluding commercial measurement instruments, those developed for large-scale state, national, and international assessments, and instruments reported in theses, dissertations, and conferences. For a comprehensive review of large-scale standardized measurement in science education, refer to Edward Britton and Steven Schneider (2007); for a comprehensive review of SMIs in science education research over the past 50 years in North America, refer to Xiufeng Liu (2009). This chapter is divided into three sections: an overview of SMIs developed since 1990 in terms of their content, target population, validation, and reliability; approaches to and issues associated with developing SMIs; and desirable future directions for developing SMIs for science education research.

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Overview of Standardized Measurement Instruments

A search for SMIs reviewed in the *Buros Mental Measurement Yearbooks* (Spies and Plake 2005) database returned only one entry. It is apparent that Buros yearbooks miss most standardized measurement instruments for science education research. A search of the ERIC database from 1990 to the present using *measurement techniques* and *science education* as descriptors returned 229 entries. After going through the abstracts and examining relevant websites cataloguing various measurement instruments, 49 SMIs reported in refereed publications were located (with the others being related to measurement instruments for science laboratories, or measurement instruments for other subjects such as mathematics, computer science, and so on). The above measurement instruments cover the following areas of science education research (the number of instruments is in the parenthesis): conceptual understanding (15), attitudes (11), cognitive reasoning (3), nature of science (5), learning environment (9), and teacher beliefs and practices (6). The list of 49 SMIs organized by the content area and then the publication year is available in the Appendix. Although these SMIs might not be exhaustive of all instruments published in refereed publications, they are likely to represent the SMIs developed in science education in the past 18 years.

Approaches To and Issues Associated with Developing Standardized Measurement Instruments

One central component of developing SMIs is to establish evidence of validity. Conceptions of validity have evolved considerably over the years. Validity used to be solely concerned with prediction. Later on, validity evolved into three types: content, criterion-related (i.e., predictive and concurrent), and construct. Validity is an integrated notion called construct validity. Establishing the construct validity of an instrument is to develop coherent and empirical arguments to support the intended interpretation or use of measurement scores (Kane 2006). Thus, there is no absolute validity; validity is closely tied to the intended interpretations and uses of scores.

Related to validity is the issue of reliability. Similarly, much change has taken place over the years in the conceptualization of reliability. Although the central concern of reliability remains the consistency of scores across repeated applications of a measurement instrument, approaches to establishing evidence of reliability have changed significantly. Generalizability theory is now the overarching conceptual framework for reliability (Haertel 2006); internal consistency as measured by KR–20 and Cronbach's alpha represent only one possible source of inconsistency in scores.

It is apparent that the above conceptual frameworks of validity and reliability have influenced the development of SMIs since 1990. The most important issues when evaluating a measurement instrument are the appropriateness of the defined construct and the intended population of the measurement instrument. An instrument validated for one population might not be valid for a different population. Only after the evaluation of these two issues should the focus of instrument evaluation shift to reported technical properties of items (e.g., item difficulty and discrimination) and the instrument (e.g., content validity, criterion-related validity, and reliability). Given that there can be a variety of different ways of establishing validity and reliability, it is important to examine the relevance of reported validity and reliability evidence to the intended use of the instrument. On the other hand, because statistics based on Classical Test Theory (CTT), which is the foundation of most of the above SMIS, are always sample dependent, and in many cases the samples used for validation are local or convenient samples, it is always necessary to continue validating an instrument.

A large number of SMIs (15) developed since 1990 are related to assessing student conceptual understanding of science concepts. This is probably due to the continued effect of the worldwide alternative conceptions movement (ACM) from the early 1970s to the l990s (Wandersee et al. 1994). Although ACM was primarily based on qualitative research, the development of many SMIs since 1990 was based on rich findings of qualitative research, which made possible large-scale diagnosis of students' alternative conceptions. Validation of the above conceptual measurement instruments has been typically based on expert content reviews for content validity and student interviews and/or factor analysis for construct validity. Because of the fact that all these instruments use multiple-choice questions, reliability is typically established based on KR–20 or Cronbach's alpha. One important issue related to construct validity is the use of diagnostic instruments for summative purposes. At issue is unidimensionality, which is concerned with the question of whether a set of items measure the same construct so that scores on the items can be summed. Without having established unidimensionality, we cannot add individual item scores to obtain a total score, which makes it impossible to compare the gains in total scores from pretest to posttest, or the difference in total scores between two curriculum innovations. Based on principal component and confirmatory factor analysis, some of the instruments (such as FCI, CSEM, CINS, and DIRECT; see Appendix) were found to be multidimensional. Using these instruments for a summative purpose could potentially undermine the construct validity of the scores.

Eleven SMIs in the Appendix are related to attitudes. The variety of standardized measurement instruments for attitudes reflects diverse theoretical frameworks related to attitude. The diversity in theoretical frameworks requires that an attitude instrument is based on a clearly defined construct. For example, Zacharias Zacharia and Angela Calabrese Barton (2004) differentiated two types of student science attitude: attitude toward progressive school science, and attitude toward critical school science. However, not all attitude instruments in the Appendix have clearly defined attitude constructs.

Six SMIs pertain to teacher beliefs and practices. One instrument made a differentiation between teacher beliefs and teacher practices (Wang and Marsh 2002). This distinction is very important because the two are not necessarily always the same. Identifying the discrepancy between teachers' beliefs and practices can inform ongoing science education reforms so that best practices promoted in university classrooms are actually implemented in K–12 classrooms. This issue also points to the critical importance of assessing actual teaching practices and their direct impact on student learning. With the exception of RTOP (see Appendix), validation of other instruments did not involve evidence of teacher practices for predicting student learning outcomes.

There are five SMIs on nature of science. Nature of science refers to the values and assumptions inherent to science, scientific knowledge, and/or the development of scientific knowledge (Lederman 1992) or, in brief, the epistemology of science as distinct from science process and content (Lederman et al. 1998). All the instruments in this section of the Appendix deal with nature of science with the exception of the subscale in VASS that deals with beliefs about learning science. Many of these instruments also adopt a Likert scale or rating scale that is often accompanied by some kind of scoring (such as scores 1–5 for Strongly Agree to Strongly Disagree). Two potential problems are associated with this practice. One problem is that there is a lack of a clear scale to facilitate qualitative interpretation. That is, what does a higher score mean, an issue pointed out by Glen Aikenhead (1973) a long time ago. Another potential problem is bias or privilege assigned to a particular version of nature of science. This problem is pointed out by Lederman et al. (1998) in their review of measurement instruments of nature of science, which still applies today. Because there is no universally agreed-upon version of nature of science, any selected response or closed-ended response question format, including a Likert scale, is likely to force students to think in terms of one version of nature of science, and it remains unclear what students' true understandings of nature of science are. In order to address the above two problems, VOSTS adopts the no-scoring approach and VNOS adopts the interview and open-ended response question format. However, one problem with this no-scoring and open-response approach is the difficulty in establishing internal consistency reliability. As Lederman et al. (1998) pointed out, a forced response format like a Likert scale can still play a role in assessing a specific version of nature of science, but a more comprehensive and accurate assessment of students' and teachers' understandings of nature of science requires a combination of both quantitative and qualitative methods.

Developing standardized measurement instruments to assess classroom and school learning environments has been very active and productive over the past four decades (Fraser 1994, 1998). This trend has certainly been continuing since 1990 (Fraser 2007). The nine SMIs included in the Appendix represent a typical approach to establishing validity and reliability of learning environment measurement instruments based on multifaceted (i.e., content, criterion-related, and construct) and multistage processes (i.e., pilot, revision, further testing, expanded testing). One trend in developing standardized measurement instruments related to learning environments is to develop various forms of a same instrument pertaining to different constructs such as personal versus class forms, preferred versus actual form, short versus long form, and so on. Another trend is that many of the instruments have been translated by or adapted to other countries or cultures, which adds to cross-cultural validation. Indeed, "few fields of educational research can boast the existence of such a rich array of validated and robust instruments" (Fraser 2007, p. 105). This wide array of SMIs has supported many productive research programs related to learning environments (Fraser 1994, 1998).

It is common to adopt the Likert scale (Likert 1932) when developing measurement instruments related to attitudes, learning environments, teacher beliefs and practices, and nature of science. The Likert scale is a “softer form of data collection” (Bond and Fox 2007, p. 101) because of the subjectivity in responding to the statements. A more serious issue associated with the Likert scale is the use of a total scale score by adding individual item scores. Values such as 1–5 assigned to five choices of a statement do not have the same origin and interval unit because they are not on a ratio or interval scale. Also, different Likert scale items have different degrees of likelihood for being endorsed. The consequence of being non-interval and having varying likelihood of being endorsed is that we cannot meaningfully add individual item scores into a total score. In order to address this issue, ways of analyzing Likert scale data that are different from using total scores should be adopted. The best way currently available is to use Rasch modeling to convert raw scores into latent scores so that respondents’ attitudes or beliefs can be measured on a latent scale, which was the case in the development of CARS (Siegel and Ranney 2003). Without using Rasch modeling, data analysis might have to stay at the individual item level. For example, responses to different items in an attitude scale can be represented by a profile and the difference in profiles between different groups or between two time points can be meaningfully compared. Because of the above potential issues with the Likert scale, alternatives to the Likert scale can be considered. Examples of such alternatives are the Thurston scale (Thurston 1925), Guttman scale (Guttman 1944), semantic differential (Osgood et al. 1971), and checklist.

Although there was a major interest in developing SMIs on student cognitive reasoning (Liu 2009) during the 1960s and 1970s, only three SMIs related to cognitive reasoning were found since 1990. The current interest seems to have shifted to metacognition (e.g., Anderson and Nashon 2007). Given Rosalind Driver and Jack Easley’s (1978) seminal review summarizing the limitations of Piagetian content-free logical reasoning in explaining students’ understanding in science, there has been less interest in measuring students’ content-free cognitive reasoning during the 1990s and 2000s. However, there is currently a demand for the development of measurement instruments that reflect both the domain-specific and development-dependent nature of children’s concept development. The development of WPSPI and IPSPI (see Appendix; Shin et al. 2003) in astronomy is consistent with this demand.

Desirable Future Directions for Developing Standardized Measurement Instruments

Developing SMIs involves three components: observation, interpretation, and cognition (NRC 2001). Observation refers to measurement tasks through which a construct is probed; interpretation refers to measurement models through which the measurement data are interpreted; and cognition refers to theories about the construct. Significant advances in all three components have taken place over the years as reviewed in this handbook. For example, new theories on student learning progression (e.g., NRC 2007a) probably will create a demand for SMIs for measuring student long-term concept development. One example of this type of instruments for measuring students' long-term concept development is PUM (Progression of Understanding Matter; Liu 2007). In terms of measurement task formats, standardized measurement instruments reviewed in this chapter have almost exclusively relied on the paper-and-pencil format. With today's technology capability, observations for measurement instruments can now be in multimedia formats or in computer modeling. In addition, many advanced measurement models are now available and already being applied in the testing industry (NRC 2001). Development of a new generation of measurement instruments in science education should take full advantage of advances in all the above three areas.

In today's context of worldwide standards-based science education reforms, there is a demand for a coherent system of assessment in which testing using standardized measurement instruments plays an important role (NRC 2007b). A coherent system of standards-based science assessment needs to be demonstrated in multiple dimensions: horizontally among various curriculum, instruction and assessment forms, vertically among different grade levels (e.g., K–12) and educational organizations (e.g., classroom, school, school district, state/provincial), and developmentally (e.g., cognitive, affective, and so on). For example, a standardized measurement instrument can be developed for both formative and summative purposes or for both classroom and large-scale state/provincial assessments. New measurement models and techniques (NRC 2001) have made it possible for students of different populations, or the same group of students at different times, to be assessed and directly compared even though they answer different sets of questions of a same standardized measurements (Bond and Fox 2007).

The ultimate goal of developing a measurement instrument is to construct a meaningful measure so that quantitative comparisons can be made. Ben Wright (1999) succinctly summarized characteristics of measures to be: (1) linear, (2) on abstract units (i.e., inferences by stochastic approximations), (3) of unidimensional quantities, and (4) impervious to extraneous factors. Developing instruments that produce measures requires new approaches. Mark Wilson (2005) proposes one such approach involving four cyclic stages: (1) defining the construct and making a hypothesis, (2) designing tasks to solicit student responses, (3) defining the outcome space in which the measured construct is demonstrated, and (4) applying a measurement model to map the observed scores into latent scores (i.e., measures) and testing the hypothesis. The above process continues until no evidence is present to reject the hypothesis. Development of the majority of the instruments reviewed in this chapter followed the classical test theory, which relies on means and standard deviations of raw scores to establish validity and reliability evidence, which would not be sufficient to produce scores as measures. Developing the next generation of measurement instruments needs to involve new measurement models such as the Rasch models (Bond and Fox 2007; Wilson 2005), or other models discussed in a national research council committee report (NRC 2001). Examples of applications of Rasch models in developing measurement instruments are available in Xiufeng Liu and William Boone (2006).

Appendix

Standardized measurement instruments reported in refereed publications since 1990

Instrument	Content	Population	Validation	Reliability	Source
Conceptual understanding					
Physical Changes Concepts Test (PCCT)	Conceptual: chemistry	High school	Content, criterion-related, and construct	n/a	Haidar and Abraham (1991)
General Science Literacy	Conceptual: General	University	Content, criterion-related	KR–20	Cannon and Jinks (1992)
Test of Understanding Graphs in Kinematics (TUG–K)	Conceptual: Physics	High school to university	Content, construct	KR–20	Beichner (1994)
Force Concept Inventory (FCI)	Conceptual: Physics	9th grade to university	Content, construct	n/a	Hestenes et al. (1992) and Hestenes and Halloun (1995)
Diffusion and Osmosis Test (DOT)	Conceptual: Biology	University	Construct	Split-half internal	Odom and Barrow (1995)
Force and Motion Conceptual Evaluation (FMCE)	Conceptual: Physics	University	Content, construct	n/a	Thornton and Sokoloff (1998)
Test to Identify Student Conceptualizations (TISC)	Conceptual: Physics	University	Content, construct	KR–20	Voska and Keikkinen (2000)
Conceptual Survey of Electricity and Magnetism (CSEM)	Conceptual: Physics	College	Content, construct	KR–20	Maloney et al. (2001)
Conceptual Inventory of Natural Selection (CINS)	Conceptual: Biology	University	Content, criterion-related, construct	KR–20	Anderson et al. (2002)
Chemistry Concept Inventory (CCI)	Conceptual: Chemistry	College	Content, criterion-related, construct	Cronbach's alpha	Mulford and Robinson (2002)

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Instrument	Content	Population	Validation	Reliability	Source
Conceptual understanding					
Testing Students' Use of the Particulate Theory (TSUPT)	Conceptual: Chemistry	University	Content, construct	Inter-rater	Williamson et al. (2004)
Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT)	Conceptual: Physics	High school to university	Content, construct	KR–20	Engelhardt and Beichner (2004)
Brief Electricity and Magnetism Assessment (BEMA)	Conceptual: Physics	College	Content, construct	KR–20	Ding et al. (2006)
Geoscience Concept Inventory (GCI)	Conceptual: Earth science	College	Construct	Rasch index	Libarkin and Anderson (2006)
Progression of Understanding Matter (PUM)	Conceptual: Chemistry	Grades 3–12	Construct	Rasch index	Liu (2007)
Attitudes					
Attitude to Science Instrument (ASI) (Short Version)	Science	Elementary school (Grs. 5–6)	Concurrent	Cronbach's alpha	Caleon and Subramaniam (2008)
Attitudes toward Science Inventory (ATSI)	Science	College	Construct	Construct	Gogolin and Swartz (1992)
Attitude toward Science Questionnaire (ASQ)	Science	Upper, middle, and lower high school	Construct	Cronbach's alpha	Parkinson et al. (1998)
Secondary School Students' Attitude toward Science	Science	Secondary school	Content, criterion-related, construct	Cronbach's alpha	Francis and Greer (1999)
Attitude toward Science	Science	Elementary school	Criterion-related	Cronbach's alpha	Pell and Jarvis (2001)
Attitude Scale (AS)	Science	Junior high school	Construct	Split-half	Kesamang and Taiwo (2002)
Chemistry Attitudes and Experiences Questionnaire (CAEQ)	Chemistry	First year university	Content, criterion-related, construct	Cronbach's alpha	Dalgety et al. (2003)

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Instrument	Content	Population	Validation	Reliability	Source
Attitudes					
Changes in Attitudes about the Relevance of Science (CARS)	Affective: Attitude	Middle and high school	Construct	Rasch index, Cronbach's alpha	Siegel and Ranney (2003)
Attitude toward Critical School Science Activity (ATCSSA) and Attitude toward Progressive School Science Activity (ATPSSA)	Affective: Attitude	Middle school	Construct	Inter-rater, Cronbach's alpha	Zacharia and Calabrese Barton (2004)
Colorado Learning Attitude about Science Survey (CLASS)	Affective: Attitude	High school and college physics	Construct	Test-retest	Adams et al. (2006)
Attitude toward Science Measures (ATSM)	Affective: Attitude	Secondary school	Content, construct	Cronbach's alpha	Kind et al. (2007)
Cognitive reasoning					
A Test of Scientific Creativity	Cognitive: Creativity	Secondary school	Content, construct	Cronbach's alpha, inter-rater	Hu and Adey (2002)
Well-Structured Problem-Solving Process Inventory (WPSPI) and Ill-Structured Problem-Solving Process Inventory (IPSPI)	Cognitive: Problem-solving	High school	Content, construct	Inter-rater	Shin et al. (2003)
Metacognition Baseline Questionnaire (MBQ)	Metacognition	High school	Content, criterion-related, construct	Crobach's alpha	Anderson and Nashon (2007)

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Instrument	Content	Population	Validation	Reliability	Source
Nature of science					
Views on Science–Technology–Society (VOSTS)	Nature of science	High school	Content, construct	n/a	Aikenhead and Ryan (1992)
Views about Sciences Survey (VASS)	Nature of science	High school and college	Content, construct	n/a	Halloun and Hestenes (1998)
Views of Nature of Science Questionnaire Form B and Form C (VNOS–B and VNOS–C)	Nature of science	Preservice and in-service science teachers	Content, construct	Inter-rater	Lederman et al. (2002)
Thinking about Science Instrument (TSI)	Nature of science	Preservice elementary teachers	Content, construct	Cronbach's alpha	Cobern and Loving (2002)
Views on Science and Education Questionnaire (VOSE)	Nature of science	Preservice science teacher	Content, construct	Cronbach's alpha	Chen (2006)
Learning environments					
Science Laboratory Environment Inventory (SLEI)	Learning environment: laboratory setting	High school and university teachers	Content, criterion-related, construct	Cronbach's alpha	Fraser et al. (1993)
Questionnaire on Teacher Interaction (QTI)	Learning environment: Teacher–student relationship	Elementary to high school	Content, criterion-related, construct	Cronbach's alpha	Wubbels et al. (1991, 1993)
Constructivist Learning Environment Survey (CLES)	Learning environment: Constructivist	Elementary to high school	Content, criterion-related, construct	Cronbach's alpha	Taylor et al. (1997)
Cultural Learning Environment Questionnaire (CLEQ)	Culturally sensitive classroom instruction	Secondary school	Content, criterion-related, construct	Cronbach's alpha	Fisher and Waldrip (1997)
What Is Happening In this Class? (WIHIC)	Learning environment: Comprehensive	Elementary to high school to university	Content, criterion-related, construct	Cronbach's alpha	Aldridge et al. (1999)

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Instrument	Content	Population	Validation	Reliability	Source
Learning environments					
Learning Environment Scales (LES)	Teacher goals and climate of cooperation	High school	Content, criterion-related, construct	Cronbach's alpha	Nolen (2003)
Outcome-Based Learning Environment Questionnaire (OBLEQ)	Outcome-based learning	Secondary school	Content, criterion-related, construct	Cronbach's alpha	Aldridge et al. (2006)
Science Teacher School Environment Questionnaire (STSEQ)	School culture	Secondary school	Content, criterion-related, construct	Cronbach's alpha	Huang (2006)
Students' Perception of Assessment Questionnaire (SPAQ)	Classroom assessment	Secondary school	Content, criterion-related, construct	Cronbach's alpha	Dhindsa et al. (2007)
Teacher beliefs and practices					
Science Teacher Self-efficacy Instrument	Teacher Beliefs and practices: Efficacy	Preservice elementary science teachers	Content, construct	Cronbach's alpha	Czerniak and Schriver (1994)
Attitudes toward Teaching of Environmental Risk (ATER)	Attitude	Science teachers	Construct	Construct	Zint (2002)
The Attitudes and Beliefs about the Nature and the Teaching of Mathematics and Science	Teacher beliefs and practices	Preservice teachers	Content, construct	Cronbach's alpha	McGinnis et al. (2002)
Teacher Perceptions and Practices Regarding the Use of the History of Science in their Classrooms	Teacher beliefs and practices	Elementary and secondary science teachers	Content	Cronbach's alpha	Wang and Marsh (2002)

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Instrument	Content	Population	Validation	Reliability	Source
Teacher beliefs and practices					
Reformed Teaching Observation Protocol (RTOP)	Teacher beliefs and practices	Science teachers	Criterion-related, construct	n/a	Admson et al. (2003)
Survey of Instructional and Assessment Strategies (SIAS)	Teacher beliefs and practices	College teachers	Content, construct	Cronbach's alpha	Walczyk and Ramsey (2003)
Science Lesson Plan Analysis Instrument (SLPAI)	Lesson planning	Elementary and secondary	Content, criterion-related	Inter-rater reliability	Jacobs et al. (2008)

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Chapter 44
Science Teaching and Learning: An International Comparative Perspective

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In international comparative studies such as the Trends in Mathematics and Science Study (TIMSS; Martin et al. 2004) and the Programme for International Student Assessment (PISA; Organisation for Economic Cooperation and Development [OECD 2007]), students' scientific competencies have been investigated repeatedly in the different cycles. Data on differences in performance find high public interest, but quickly lead to questions concerning conditions in the educational system that are responsible for the observed differences in the outcomes of schooling. As the design of these studies includes the administration of student and school questionnaires, one expects to at least obtain hints about factors on different levels of the school system that have an impact on the development of competencies. Jürgen Baumert et al. (2001), for example, name the organisation of school systems, the social and cultural background of the students, the characteristics of the school, the curriculum, teachers, parents and peers, as relevant factors as well as indicators typically considered in the questionnaires. From an educational perspective, however, the science classroom is the most interesting and important level and environment. The science classroom is the place where young adults all over the world are systematically made familiar with science over a long period of time (OECD in prep.). Therefore, the investigation of science teaching and learning in an international comparison is of special interest in order to understand the differences in students' scientific competencies displayed.

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The international comparison of classroom teaching stood at the core of the TIMSS Video Studies (Hiebert et al. 2003; Roth et al. 2006) in order to identify culturally different patterns of teaching and learning in the mathematics and science classrooms of a small number of countries. The results of these studies show that one cannot identify a single method, strategy or way of teaching that is successful for student learning. In fact, science teaching and learning in high-performing countries such as The Netherlands, Australia or Japan seems to be conducted in largely differing ways. These results imply that the international comparison of classroom teaching and learning mainly provides countries with the possibility to learn from each other and be inspired by different ways of teaching (Prenzel and Seidel 2009).

Even though the international comparison of classroom teaching bears great potential, until now, the empirically approved knowledge which has been gained about effective science teaching and learning in an international comparison is only limited. This is because of the many constraints that arise when trying to investigate and compare science teaching around the world. First of all, the international comparison of science teaching and learning is cost intensive, especially when classroom videos are recorded and analysed. That is the reason why video studies often focus on a small number of selected countries. Another possibility for obtaining information on international science teaching and learning is the use of student questionnaires. These questionnaires are much less cost intensive than video studies. There is, however, an ongoing discussion concerning the reliability and validity of students' descriptions of their science classrooms, because students in different countries might choose different frames of references (Baumert et al. 2004). An application of teacher questionnaires for assessing characteristics of their instruction leads to similar or even larger problems (Kunter and Baumert 2006).

As the international comparative investigation of science teaching and learning is a complex task involving many challenges, this chapter aims to provide an insight into recent approaches to investigating science teaching and learning in an international comparison. It first discusses two different approaches to internationally comparing science teaching and learning. Subsequent to this, the role which central findings from research on teaching effectiveness play in the development of students' questionnaires is discussed. Furthermore, the chapter introduces different ways of analysing and presenting the data. Finally, perspectives for future research in international comparative science teaching and learning will be discussed.

Approaches to Investigating Science Teaching and Learning in an International Comparison

The international comparison of science teaching and learning provides countries with information on different ways of teaching science. Until now, studies like TIMSS (Martin et al. 2004) and PISA (OECD 2007) are the only source of reliable and representative data on science teaching and learning in many countries. In these studies, the characteristics of science classrooms are investigated along with a number of other contextual factors which contribute to students' development of scientific literacy. In order to gain an insight into different approaches to investigating science teaching and learning in an international comparison, these two large-scale studies will be outlined.

TIMSS – The Trends in Mathematics and Science Study

According to Ina Mullis et al. (2005) TIMSS has been assessing fourth and eighth grade students' mathematics and science achievement, along with a number of contextual factors, in a regular 4-year cycle, since 1995. The study is based on the 'TIMSS curriculum model'. This model encompasses: (1) the intended curriculum which represents the mathematics and science content which students are supposed to learn in school; (2) the implemented curriculum asking what is actually taught in the classroom, who teaches it and how it is taught; and (3), the achieved curriculum in terms of what students have actually learned in mathematics and science. Science teaching and learning is investigated as part of the implemented curriculum by means of student and teacher questionnaires. These questionnaires mainly evaluate the organisational aspects of science lessons such as the instructional activities. The curriculum model establishes the link between science teaching in the classroom and students' science achievement, assuming that the implemented curriculum will influence the achieved curriculum. However, the relationship between these two is not systematically investigated in TIMSS. Accordingly, the findings from the TIMSS studies focus on the description of science teaching and learning in terms of the organisational aspects of the classroom.

In addition to the 1999 cycle of the TIMSS assessment of science achievement, a science video study was conducted. In the TIMSS 1999 Science Video Study, science teaching and learning was compared in a representative sample of eighth grade science classrooms in five countries (Australia, Czech Republic, Japan, The Netherlands and the USA). Kathy Roth et al. (2006) propose a specific framework for the collection of video data and the development of analytic instruments, in which the lesson is emphasised as the main unit of analysis. This framework not only considers the actions of the teacher as central to classroom teaching but also the students' actions and the science content that is taught. The guiding research question in this framework is: What opportunities did the lesson provide for students to learn science? This main research question is broken down into three sub-questions: (1) How did the teacher organise the lesson to support students' opportunities to learn science? (2) How was science represented to students in the lesson? (3) What opportunities did students have to participate in science learning activities? For each of these research sub-questions, reliable coding systems were developed in order to describe science teaching and learning in the different countries. With regard to the teacher actions, the way in which the lesson was organised was investigated; for example, how much they worked with the whole class compared to individual work. Again, the investigation of science teaching and learning in the

TIMSS 1999 Science Video Study (Roth et al. 2006) focuses on the organisational aspects of the classroom. Links between the classroom characteristics and the students' learning are hardly established.

PISA 2006 – The Programme for International Student Assessment

The Programme for International Student Assessment (PISA) investigates 15-year-old students (OECD 2007). The aim of PISA is to assess whether students around the world in this age group are prepared for life in modern society. Therefore, the PISA assessment does not focus on particular curricular science topics, but rather investigates whether such students have developed the scientific literacy that enables them to successfully participate in society (OECD 2006). In PISA 2006, in-school science lessons are considered an important opportunity for all students to systematically engage in science activities and to develop scientific literacy (OECD in prep). Therefore, the science teaching and learning in all of the participating countries were investigated.

The assessment of science teaching and learning in PISA 2006 was systematically conducted from the students' perspectives and focused on characteristics that could be observed and reported by the students with a high degree of reliability and validity. The student questionnaire was developed based on a comprehensive model of teaching and learning proposed by Tina Seidel and Manfred Prenzel (2006), which enabled a close link between science teaching and students' scientific literacy to be established. Furthermore, the teaching and learning activities focused upon in the investigation were derived from a thorough review of research literature. As this approach is innovative and differs largely from the approach taken in TIMSS, the development of the framework and the questionnaire used in PISA 2006 will be discussed in more detail.

Findings from Teaching Effectiveness Research

The contextual framework for the student questionnaire in the PISA 2006 survey is based on a comprehensive model of science teaching and learning (Seidel and Prenzel 2006). This model is the foundation for the development of the questions investigating science teaching and learning from the students' perspective in PISA 2006. It was proposed on the basis of the current state-of-the-art in research on science teaching and learning as summarised in a meta-analysis by Tina Seidel and Richard Shavelson (2007) and encompasses four components: (1) the impact of student prerequisites on teaching and learning; (2) teaching that provides opportunities for the students to engage in science; (3) the students' perception, acknowledgement and processing of science-related information that is provided by teaching; and (4), the students' development of scientific literacy. This model links the contextual framework for science teaching and learning to the PISA framework for the assessment of students' scientific literacy. In addition, results from teaching effectiveness research were considered in order to define the focus of the investigation of science teaching and learning in international classrooms. The PISA framework for the assessment of students' scientific literacy emphasises that scientific knowledge needs to be embedded in meaningful contexts. Furthermore, this framework distinguishes between three aspects of scientific literacy: The competence (1) to identify scientific issues, (2) to explain phenomena scientifically, and (3) to use scientific evidence (OECD 2006). Based on findings from teaching effectiveness research which indicate how the development of these three competencies can be fostered, the following five areas were proposed as foci for the investigation of science teaching and learning in PISA 2006: Lesson Time, Interactive Science Teaching and Learning, Hands-on Activities, Student Investigations and Real-life Applications. These will now be discussed in turn.

Lesson Time

Science learning takes place in different in and out-of-school settings, but the availability of out-of-school opportunities to learn science is largely dependent on a student's social background. Therefore, school is the place where all students are regularly provided with opportunities to learn about scientific content, scientific methods and ways of thinking. Results from teaching effectiveness research points out that opportunities to learn – especially in terms of time to learn – are an important prerequisite for the development of scientific competency (Seidel and Shavelson 2007). These results highlight that sufficient opportunities to develop scientific literacy need to be provided in terms of in-school lesson time, but can also be offered in out-of-school lessons or by studying individually. Therefore, lesson time is one of the aspects of science teaching and learning investigated in PISA 2006.

Interactive Science Teaching and Learning

Within the framework for the assessment of scientific literacy in PISA 2006, the competency to explain scientific phenomena is highlighted as one important aspect. In order to establish this competency, it is important for students to be actively involved in classroom discourse concerning scientific topics. John Bransford and Susan Donovan (2005) suggest that this can support students in acquiring a specific language to communicate about scientific concepts and to experience the importance of discourse for scientific enquiry. Science educators such as, for example, Avi Hofstein and Vincent Lunetta (2004) nowadays agree that orientation of science teaching towards interactive elements can foster students' learning. This is also supported by a number of studies, for example, the one by Reuven Lazarowitz et al. (1996) showing that interactive elements in science teaching have a positive impact on students' cognitive as well as motivational learning outcomes.

Hands-on Activities

The PISA 2006 framework for scientific literacy highlights the competency to use scientific evidence to draw conclusions. In order for students to practise this skill, they need scientific evidence or data. Hands-on activities in the science classroom provide students with the opportunity to gain their own data. Results from teaching effectiveness research point to the fact that hands-on experiments in the classroom have positive effects on the affective aspects of students' scientific literacy such as interest and attitudes towards science (e.g., Baumert and Koeller 2000). However, it is also emphasised that hands-on activities need to be embedded in the larger context of investigating scientific questions in order to support student learning processes (Singer et al. 2005).

Student Investigations

In order to establish the three competencies stated in the PISA 2006 framework for the assessment of scientific literacy, students need to be provided with opportunities to engage in such activities. Student investigations in science teaching and learning aim to involve students in the broader process of scientific research; therefore, students are involved in the phrasing of scientific questions, the design of scientific investigations and the interpretation of the data. Student investigations in science teaching and learning go beyond the hands-on experiments mentioned above and involve students in the process of scientific enquiry (Hofstein and Lunetta 2004). Student investigations include activities in which the students test their own ideas using scientific methods. Thus, the degrees of freedom are much larger than in hands-on activities. A recent review by Jaap Scheerens et al. (2005) of enquiry studies provides positive evidence for the impact of student investigations on students' scientific literacy. Furthermore, a study by Susan Singer et al. (2005) stresses the idea that hands-on experiments can support students' development of scientific literacy if they are integrated into instructional units with the aim to improve the ability of students to think and reason scientifically; that is, to be involved in scientific investigations.

Real-Life Applications

If students are supposed to be able to use the knowledge of and about science acquired in the classroom in the natural world, real-life applications are of special importance. Real-life applications in science teaching and learning help students to understand the relevance of scientific concepts for the world outside school. In traditional science teaching, real-life applications are usually not a major focus (e.g., Seidel 2003). However, different studies in real classroom settings (e.g., Fey et al. 2004), as well as in computer-supported learning environments, show the positive impact of real-life applications on students' scientific literacy (Cognition and Technology Group at Vanderbilt 1997).

The student questionnaire in the PISA 2006 assessment focuses on these five areas of science teaching and learning for different purposes. First of all, this approach to the development of the student questionnaire leads to an international comparison of science teaching in terms of classroom activities which have the potential to support student learning. Furthermore, the focus on lesson characteristics which support learning processes in general, ensures that these characteristics are relevant in all the countries tested (Seidel and Shavelson 2007). To gain a reliable description of these science teaching and learning activities, the questions refer to observable events to make it easier for the students to evaluate lesson characteristics in a way that is independent of subjective comparison. Accordingly, the items in the student questionnaire contain statements which are closely related to lesson events and teachers' as well as students' behaviour. They ask about the frequency with which clearly definable teaching and learning activities occur in science lessons.

This description of the framework for the development of the student questionnaire in the PISA 2006 assessment highlights the potential of the use of recent findings from teaching effectiveness research for the international comparison of science teaching and learning. This approach to developing the student questionnaire not only enables a reliable description of science teaching and learning, the close link between the framework for the investigation of science teaching and students' scientific literacy makes it possible to also investigate the effects of science teaching on student learning.

Data Analysis and Presentation

The two large-scale studies presented above employed different strategies to analyse and present data describing science teaching and learning in an international comparison. In the TIMSS 1999 Science Video Study (Roth et al. 2006), the lesson is the unit of analysis. In this study, the description of science teaching and learning is conducted by presenting the percentages of lesson time which are devoted to certain teaching activities. For example, the results show that the percentage of lesson time actually used for science instruction (as opposed to time devoted to the organisational aspects of the lesson) varies between 91% and 97% in the investigated countries. Therefore, the results of this study provide a detailed description of science lessons in the investigated countries. They resemble what actually happens in the classroom very closely, but they only represent one lesson within the course of the school year.

In contrast, in the survey studies associated with TIMSS, students' and teachers' statements concerning science classrooms refer to the whole school year. In the report by Michael Martin et al. (2004) the teachers' statements are presented as the percentage of students whose teachers report using certain activities in most or every lesson. Similar analyses are conducted for the student questionnaire. To conclude, the TIMSS survey and the TIMSS Video studies provide a detailed description of the characteristics of science teaching and learning in an international comparison. This description is mostly concerned with the organisational aspects of the science classroom and the systematic relationship with the science achievement of the students is not explicitly investigated.

The analyses of the student questionnaire used in PISA 2006 also refer to the whole school year. In this study, the analyses describing science teaching and learning from the students' perspective display the percentages of students reporting that certain activities occur in most or all of their science lessons during the course of the school year. Table 44.1 displays data from PISA 2006 on the frequencies of elements of interactive science teaching as an example.

As Table 44.1 shows, the majority of the 15-year-old students in the OECD countries report that interactive science teaching activities occur in their classrooms on a regular basis. Especially, the activities 'Students explain ideas' and 'Students state opinion' are reported frequently.

In addition to the description of science teaching and learning on an item-by-item basis, the analyses in PISA 2006 went one step further and tried to identify patterns of science teaching and learning in international classrooms. In order to investigate different patterns of science teaching and learning, a typological approach was used (Seidel et al. 2007; OECD in prep). Figure 44.1 displays the three different patterns identified.

The three different patterns of science teaching and learning displayed in Fig. 44.1 can be identified in all of the investigated countries (OECD in prep.). *Pattern 1:* The first pattern is characterised by ample opportunities for the students to engage in all of the science teaching and learning activities encompassed in the analyses. *Pattern 2:* Students in the second pattern have lots of opportunities to engage in cognitive tasks such as drawing conclusions from experiments or explaining their own ideas, but they less often conduct hands-on activities such as designing or conducting their own experiments. *Pattern 3:* The third pattern encompasses students who have very few opportunities to engage in hands-on activities as well as in cognitive activities. Even though these patterns can be identified in all of the investigated countries, the percentages of students in the different patterns varies between the countries. Overall, Pattern 2 is the pattern which is observed most frequently. The least frequent pattern is Pattern 1 (Seidel et al. 2007).

In a last step, the different patterns of science teaching and learning identified were used to investigate their interrelation with students' scientific literacy. Beforehand, the relationship between students' lesson time and their scientific literacy was also investigated. The results of the analyses show that students attending 4 h, or more of science lessons every week reach significantly higher levels of scientific literacy than students experiencing less than 2 h of science teaching per week (Seidel et al. 2007). Furthermore, students in the first science teaching and learning pattern (Pattern 1) display significantly lower scientific competency than students in both other patterns (Patterns 2 and 3). The most successful pattern with

Table 44.1 Interactive science teaching in the OECD countries (Seidel et al. 2007, p. 154). Percentages of students stating that these activities occur in most or all of their science lessons

	Students explain ideas		Students state opinion		Class debate or discussion		Students discuss topics	
OECD countries	%	(*SE*)	%	(*SE*)	%	(*SE*)	%	(*SE*)
Australia	71	(*0.6*)	54	(*0.6*)	41	(*0.7*)	55	(*0.7*)
Austria	54	(*1.2*)	53	(*1.2*)	55	(*1.1*)	48	(*1.2*)
Belgium	68	(*0.8*)	32	(*0.7*)	30	(*0.8*)	32	(*0.7*)
Canada	73	(*0.7*)	53	(*0.7*)	37	(*0.7*)	54	(*0.7*)
Czech Republic	70	(*0.8*)	37	(*1.1*)	51	(*1.1*)	42	(*1.1*)
Denmark	54	(*1.2*)	51	(*1.1*)	41	(*1.0*)	39	(*0.9*)
Finland	64	(*1.0*)	51	(*1.0*)	13	(*0.9*)	37	(*0.9*)
France	66	(*1.0*)	36	(*0.9*)	24	(*0.8*)	36	(*0.8*)
Germany	59	(*0.9*)	56	(*0.8*)	40	(*0.9*)	45	(*0.8*)
Greece	59	(*0.9*)	65	(*0.8*)	74	(*0.8*)	66	(*0.8*)
Hungary	57	(*1.0*)	61	(*1.0*)	32	(*1.1*)	65	(*1.0*)
Iceland	62	(*0.7*)	57	(*0.8*)	7	(*0.4*)	49	(*0.8*)
Ireland	51	(*1.0*)	41	(*0.9*)	20	(*0.8*)	32	(*1.0*)
Italy	76	(*0.6*)	55	(*0.6*)	48	(*0.7*)	52	(*0.7*)
Japan	34	(*1.1*)	17	(*0.6*)	4	(*0.3*)	9	(*0.6*)
Korea	23	(*0.9*)	22	(*0.7*)	11	(*0.7*)	9	(*0.7*)
Luxembourg	59	(*0.8*)	46	(*0.7*)	33	(*0.7*)	41	(*0.7*)
Mexico	78	(*0.6*)	59	(*0.7*)	37	(*0.7*)	51	(*0.8*)
The Netherlands	48	(*1.0*)	47	(*0.9*)	29	(*0.9*)	27	(*0.7*)
New Zealand	71	(*0.8*)	50	(*1.0*)	40	(*1.0*)	51	(*1.1*)
Norway	61	(*1.0*)	47	(*1.0*)	52	(*1.0*)	41	(*1.1*)
Poland	50	(*0.8*)	56	(*0.9*)	37	(*1.0*)	44	(*0.9*)
Portugal	74	(*0.9*)	67	(*0.9*)	45	(*1.0*)	52	(*0.9*)
Slovak Republic	51	(*1.0*)	41	(*1.1*)	36	(*0.9*)	37	(*1.1*)
Spain	69	(*0.6*)	58	(*0.7*)	24	(*0.6*)	31	(*0.8*)
Sweden	63	(*1.0*)	41	(*1.2*)	43	(*1.2*)	30	(*1.0*)
Switzerland	65	(*0.7*)	50	(*0.8*)	29	(*0.8*)	45	(*0.8*)
Turkey	74	(*0.8*)	70	(*0.9*)	49	(*0.8*)	56	(*0.8*)
UK	72	(*0.8*)	50	(*0.7*)	38	(*0.7*)	44	(*0.8*)
USA	74	(*0.8*)	56	(*0.8*)	47	(*1.3*)	59	(*0.7*)
OECD Average	62	(*0.9*)	49	(*0.9*)	36	(*0.8*)	43	(*0.8*)

regard to scientific competency is the second pattern, in which students have ample opportunities to be cognitively engaged but only have some opportunities to engage in hands-on activities. With regard to interest, the first pattern is the most effective one. The lowest interest is displayed by students in the third pattern. However, due to the cross-sectional design of PISA, these results need to be interpreted carefully. To conclude, the analyses in PISA 2006 go beyond the mere description of science teaching and learning in an international comparison and also consider the effects of science teaching patterns on students' scientific literacy.

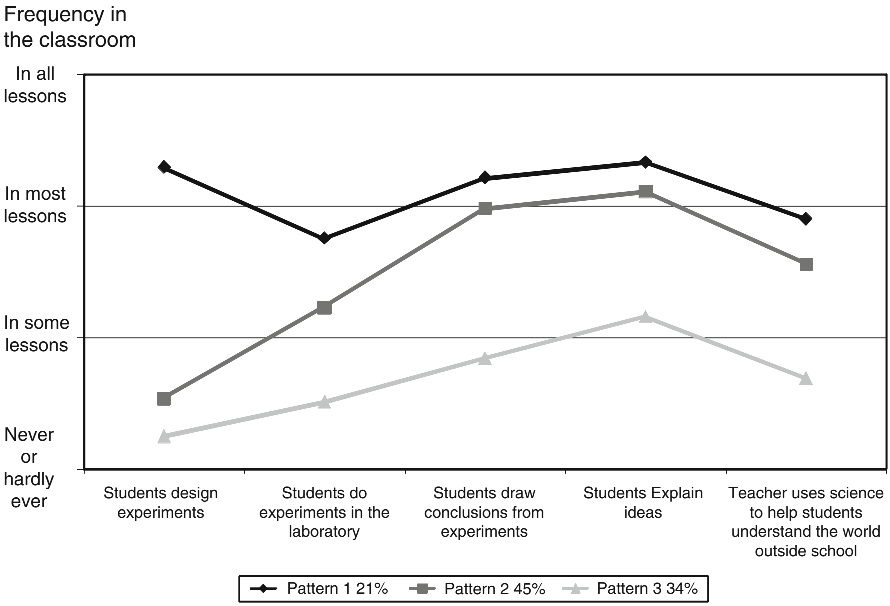

Fig. 44.1 Three different patterns of science teaching and learning in the OECD countries based on a Latent Class Analysis using five selected items (Seidel et al. 2007, p. 165)

Perspectives on Research in Science Teaching and Learning

Science teaching and learning is often part of the contextual frameworks of studies investigating students' scientific literacy or achievement such as TIMSS (Martin et al. 2004) or PISA (OECD 2007). The main focus of these studies is the assessment of students' competencies. Therefore, the development of instruments to evaluate students' competencies was conducted very cautiously. The development of items to investigate contextual factors such as science teaching and learning is usually not emphasised. In PISA 2006, the development of the contextual framework for the investigation of science teaching and learning was carried out based on recent findings from teaching effectiveness research. The close link between the state-of-the-art in teaching effectiveness research and student questionnaire development enables a detailed description of science teaching and learning activities which support student learning from an international comparative perspective. In addition, the analyses in PISA 2006 also provided an insight into the systematic relationship between science teaching and learning and the students' scientific literacy. Due to the cross-sectional design of the PISA study, these analyses do not prove a causal relationship between certain teaching patterns and better student competencies. This highlights the need for further research investigating international science teaching and learning in a longitudinal design in order to yield information concerning the effects of science teaching on student learning processes and outcomes. Furthermore, the results yielded by the video studies compared to the survey studies point to the specific potential of video research. Therefore, future research could also combine different methods (video analysis, teacher questionnaires, and student questionnaires) in order to gain a more comprehensive picture of science teaching and learning in an international comparison.

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Chapter 45
Focusing on the Classroom: Assessment for Learning

Bronwen Cowie

Introduction

Teachers are required to conduct assessment in the classroom for a variety of purposes, including data for monitoring the system and school accountability, the award of individual qualifications, and informing teaching and learning. However, following the review by Black and Wiliam (1998), the central role of formative assessment in shaping teacher and student classroom experiences has come in for special attention. Formative assessment, also referred to as assessment for learning, is a process in which teachers and students recognise and respond to student learning, during that learning. Typically it is embedded in teacher–student interaction, but it also involves planned tasks: an assessment is formative when the assessment information is used to enhance teaching and learning. In practice, formative assessment depends on the dynamics of the interaction between curriculum, teaching and learning and, in turn, this is underpinned by a conception of learning, learners/students and what it means to know. This chapter explores the proposition that socio-cultural views of learning offer new insights and opportunities for the classroom practice of assessment, including formative assessment.

Assessment and Views of Learning

How learning and the learner are viewed shapes what counts as evidence of learning and the type of activity that might comprise assessment of and for learning. A constructivist view of learning underpinned initial formulations of formative assessment

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(Sadler 1989). This view supports the use of clear goal statements and success criteria, targeted feedback and student self-assessment. Social views of learning draw attention to the role of social interaction and support the efficacy of peer assessment and discussion. Current research and theorising are exploring the implications for classroom assessment of a variety of socio-cultural conceptions of learning (Gipps 1999). Learning from a socio-cultural perspective revolves around issues of belonging and the transformation of participation and identity. This shifts the focus from what is in a student's mind to student actions and interactions in a particular social, cultural and material setting where certain goals and practices are valued above others. What counts is not just what students know, although this is important, but also the development of students' identities as capable and competent learners (Gipps 1999). A socio-cultural orientation draws attention to the temporality of learning and knowing: what, why and how students are learning is also of interest. All this has implications for the conceptualisation of student active engagement in assessment for learning. Socio-cultural views problematise the notion of assessment as a tool for measuring individual achievement and challenge the assumption that it is possible to decouple learning outcomes from the learning process and the social, material and historical context of the classroom in which learning and the assessment of it takes place. The shift to a socio-cultural view of learning in science education has informed, and been informed by, the debate about the nature of the outcomes of value in science education.

The Curriculum and Classroom Assessment

Assessment and curriculum interact in complex ways. Science curricula have undergone a number of transformations, most notably from a focus on content knowledge to a focus that Richard Duschl (2008) sums up in terms of three integrated domains: conceptual structures and cognitive processes; epistemic frameworks used when developing and evaluating scientific knowledge; and the social processes and contexts that shape how knowledge is communicated, represented, argued and debated. These expanded curriculum goals have implications for pedagogy and assessment, particularly at a time when relatively greater importance is being accorded to assessment. Official curricula are at the start of a cascade of interpretations. The intended curriculum becomes an implemented curriculum and then an experienced and achieved curriculum through a dynamic interaction between curriculum, assessment and pedagogy. This constructs local meanings for being students, teachers and the discipline. The strategic value attributed to teacher classroom assessment in shaping curriculum and student experience is clearly signalled by the current substantial investment in the development of resources to support teacher classroom-based assessment.

The Classroom as the Site for Assessment

Formative assessment is based on the principle that students need to become more then consumers of assessment activity (Sadler 1989). By foregrounding the promotion of student autonomy (power with students), this principle has the potential to disrupt the traditional power balance in classrooms (Gipps 1999). Its enactment can require the renegotiation of teacher and student roles and responsibilities. A socio-cultural view of learning directs attention towards classroom interaction as a locus for formative assessment (Bell and Cowie 2001).

Student opportunities to participate actively in assessment for learning interactions are inextricably entangled with the discourse of power that is in operation in a particular classroom (Munns and Woodward 2006). This discourse includes what counts as knowledge, who has access to really useful knowledge, who has ability, who controls the teaching space, who is valued as an individual and a learner, and whose voice is given credence. The social norms and practices of a classroom not only make meaning public, but also position learners in particular ways in relation to their being active generators of knowledge. For instance, the sequence of teacher question–student response–teacher evaluation, common to many science classrooms (Lemke 1990), constitutes teachers as people with authority over students and knowledge. The tendency for teacher questions and evaluations to incorporate the language of science further contributes to teacher authority over the subject and students. For students to generate knowledge as part of social practices they must be given the authority for and the resources with which to build knowledge. The idea of authorative and accountable positioning with conceptual agency suggests being entitled and expected to move about the environment freely, with access to resources throughout the environment and with the authority to use, adapt and combine those resources in unconventional ways (Greeno 2006).

Research by Rosalind Driver, John Leach, Robin Millar and Phil Scott (1996) has highlighted that student decision making in science can involve: their acceptance of the authority of the teacher, text or peer as the 'final warrant of viability'; their testing the coherence of their explanation in comparison with other knowledge claims; and their testing the ability of their explanation to predict what happens in a practical situation. Students interviewed by Bronwen Cowie (2005a) used a similar range of criteria to evaluate their ideas. Bronwen Cowie and colleagues (Cowie et al. 2008; Glynn et al. 2008) demonstrate the efficacy of teacher use of multiple and multi-modal means to make their learning intentions and criteria of quality explicit, as well as supporting the use of a range of sources of knowledge as feedback. While teacher talk as feedback was, and is likely to remain, the main source of individualised feedback, students also consulted peers, books and people outside the classroom and conducted trials and tests.

Studies in science education that adopt a socio-cultural perspective provide insights into classroom environments that are supportive of student agency and therefore would support a culture conducive to assessment for learning. Randi Engle and Faith Connat's (2002) work on productive disciplinary engagement is one example. Work in the development of student skills of argumentation provides many of the tools that students need to engage in productive self-assessment through consideration of the linkages between evidence and explanation (Simon et al. 2006). There is, therefore, potential for productive dialogue between researchers working in these domains and those working in formative assessment.

Teachers and Classroom Assessment

Despite the research evidence, assessment is still not widely used by teachers to promote learning. Reasons for this include factors external to schools, such as international and national testing regimes, school-level factors such as parent community expectations, and teacher personnel factors (Carless 2005; Tierney 2006).

Juggling Competing Imperatives

Teachers face competing demands in their classrooms. On the one hand, there are the imperatives to support the learning of *all* the students in their classes. On the other hand, teachers are expected to collect evidence that demonstrates the efficacy of their work for system and school accountability purposes. These two competing demands play out in the tensions between formative and summative assessment. In contrast to formative assessment, for which the intention is to enhance learning (assessment for learning), the purpose of summative assessment is to sum up and make a judgement about student learning (assessment of learning). This distinction explains why continuous summative assessment is not formative assessment. A key question for teacher workload is whether or not a task can be used for formative and summative purposes. Paul Black et al. (2003) found that data from a summative task could be reinterpreted to meet a formative function. Formative data can be summarised and synthesised over time to produce a summative assessment that encompasses the 'how' and 'why', as well as the 'what', of student learning (Anderson et al. 2007; Cowie et al. 2008). Unfortunately, student sensitivities to the difference between teacher evaluation of their learning and teacher interest in their ideas pose a challenge to suggestions that teachers can exploit the synergies between formative and summative assessment (Cowie 2005b; Reay and Wiliam 1999; Tunstall and Gipps 1996).

Teacher formative assessment is also a site where the dynamic tension between teachers' responsibilities towards the curriculum and the class, and for individual students, plays out in practice. Beverley Bell and Bronwen Cowie (2001) emphasise the dynamic responsive and dilemma-driven nature of formative assessment. Their research indicated that teachers undertook planned and interactive formative assessment, which focused on teacher-intended learning outcomes and students' actual interests and ideas, respectively. Interactive formative assessment involved the teacher in noticing, recognising and responding to assessment information in a manner congruent with Royce Sadler's (1989) claim that formative assessment requires connoisseurship: teachers called up science and student self-referenced criteria and actions that were salient in the moment. Adding complexity, Beverley Bell and Bronwen Cowie (2001) found that primary teachers were concerned about fostering student personal, social and science learning. Student personal development related to students' learning about themselves as learners and learning-to-learn. Students' social development related to the skills that students needed to participate in group work and discussion. Students' science learning related to their learning of science content, science processes, and the ways in which science linked to their everyday lives (Cowie et al. 1996). Teachers claimed that both the planned and interactive forms of formative assessment and the switching between them were hallmarks of a competent teacher.

A Knowledgeable and Skilled Activity

Knowledge of a range of assessment practices that complement the curriculum and inform teaching and learning has come to be seen as a core competency. Teachers need to be knowledgeable about and able to use various strategies to find out about student ideas, to be able to recognise the point of development reached by their students, and to have strategies for developing student ideas. Teachers need a deep understanding of: the subject matter to be taught; a clear idea of the progression of ideas and skills that are the goals of student learning; and of the pathways that students are likely to take in this development. Formative action is enhanced if a teacher is able to take into account a student's prior understandings, effort, progress and particular circumstances at the time. A teacher's knowledge of when and where students can do something enriches, rather than biases, their interpretations. In addition, teachers need to be able to identify and communicate their learning goals and criteria of quality, while taking note that tightly specified criteria can foster a culture of compliance rather than learning (Torrance 2007).

It takes time for teachers to embed formative assessment into their classroom (Black et al. 2003; Webb 2009). Studies by Dylan Wiliam et al. (2004) and Alister Jones and colleagues (Cowie et al. 2008; Jones et al. 2001) provide evidence that a focus on teacher planning can enhance teacher formative practice. Jones and colleagues show that the use of a science-specific planning framework can enhance teacher pedagogical content knowledge (Shulman 1987) and this leads to enhanced teacher formative assessment interactions and enhanced student learning. How to scale these gains is a key question for policy makers and researchers alike.

Considering synergies across the field of science education, a first step in teacher formative assessment involves teachers in generating information on student learning. Research on student alternative conceptions and teaching for conceptual change has contributed a substantial body of tools and tasks that can be used to elicit student ideas in context. There is research that explores and seeks to exploit the formative potential of strategies such as concept maps, predict–observe–explain tasks, and the use of different contextual and material prompts and probes. The area of teacher inference is under-researched and key to the validity of teacher assessment (Gitomer and Duschl 1998). However, knowledge of student alternative conceptions can inform teacher interpretations of teacher actions. Work on student learning progressions is being developed to inform teacher assessment interpretations and feedback (Wilson 2009). Science education research also has a contribution to make to teacher feedback and actions to guide student thinking. Teaching approaches involving development and cognitive conflict have the potential to inform teacher's feedback actions once they understand student thinking.

The Role and Importance of Teacher Beliefs

Teacher beliefs about teaching, learning, assessment and curriculum and their interrelationship influence teacher formative assessment practice (Bell and Gilbert 1996; Sato et al. 2005). Teacher realisation that teaching and assessment can be integrated activities is important (Treagust et al. 1999). Teachers who implement the recommended formative assessment strategies (such as wait-time) without a concurrent focus on student agency achieve what Bethan Marshall and Mary Jane Drummond (2006) describe as the 'letter' rather than the 'spirit' of formative assessment or assessment for learning. As Paul Black and his colleagues note, formative assessment is not necessarily or inevitably a benign or expansive process, nor is it one that always promotes 'learning autonomy' (Black and Wiliam 2006). For example, professional development that focuses on questioning and strategies for giving feedback alone is not enough. How teachers react to students' responses to their questions plays a role in opening up, or restricting, interaction and consequently teacher and student opportunities in assessment for learning. Heather Smith and Steve Higgins (2006) propose that teacher reactions are grounded in teacher understandings of the relationship between the talk that they use for teaching, and the talk that they hope their students will use for learning. Understandings of these linkages may need to be challenged if teachers are to genuinely engage students in formative assessment.

Students and Classroom Assessment

The principles of formative assessment converge with socio-cultural views of learning in foregrounding the need to consider students as active and intentional participants in classroom assessment practices. Although very few researchers have sought students' views about their classroom assessment experiences, those who have done so have found students to be critical and constructive commentators on their experiences. Student commentary has highlighted the multiple consequences of classroom assessment for them, the importance of trust and respect, the influence of their goals and learning motivations, and equity issues (Cowie 2005a).

Multiple Consequences

Student commentary about their experiences of classroom assessment, foreground the issues of consequential validity (Messick 1994). From an assessment perspective, this is a key criterion of quality for formative assessment that gains authenticity when action is taken by teachers and students to enhance student learning. Classroom assessment impacts on student learning, interpersonal relationships and students' sense of self-efficacy, self-esteem and motivation (Black and Wiliam 1998; Cowie 2005b; Crooks 1988; Hickey and Zuiker 2005). From a socio-cultural perspective, students' descriptions of their experiences construe classroom assessment as a social process that plays a key role in the ongoing construction and reconstruction of students' public identities and perceptions of themselves as a competent, or not, learner and knower of science in both the short and long term. A student might identify as someone who enjoyed and learned science in the classroom or as someone who was 'useless' at science, and all the variations in between (Cowie 2005a). Continuity of teacher–student relationships is important in this. The messages about what is considered important to learn, how to learn and who is important are interpreted in context.

The Importance of Trust and Respect

Teachers and students have not only a shared past but also a shared future, with the future that they anticipate influencing their actions. This continuity of relationships can contribute to and or constrain student participation in assessment. Mutual trust and respect are central to students' active participation in formative interactions when they are working at the edges of their understandings. Student trust that teacher responses to their questions are likely to be beneficial and not harmful is important. They also need to trust that teachers' advice will be helpful. Conversely, teachers need hold high expectations and trust in students' desire to learn if interactions are to optimise student learning.

Student Goals and Learning Motivations

Students' engagement in formative self-assessment that is aligned with teacher goals for their learning requires that they share and value these. Classroom research indicates that students are motivated to achieve social as well as academic goals and that these are often intertwined. In terms of social goals, students work to develop positive social identities and to maintain and establish positive interpersonal relationships with peers and teachers. With respect to student achievement motivation, it appears that, when students pursue learning goals (i.e. they seek to understand ideas), they tend to view assessment as a joint teacher–pupil responsibility. In the study by Bronwen Cowie, students who intimated that they were interested in understanding ideas advocated teacher feedback in the form of suggestions that provided an active role for them in making sense of ideas. Conversely, when students intimated that they had been pursuing task completion (a performance learning motivation Carol Dweck 1986), they expressed a preference for the teacher helping them to do this. They viewed as unhelpful teacher actions involving eliciting information about their thinking because this took time away from their working on a task. On these occasions, students described assessment as a teacher responsibility; students saw no role for themselves in seeking to help to extend their understanding. Paul Black and Dylan Wiliam (2006) note that students can change their learning identity from passive to active in classrooms that focus on assessment for learning.

Equity Issues

Given that different task formats offer different opportunities for students to express what they know and can do and that different students respond to the same task in different ways (Lokan et al. 1999), it is important that the students have a variety of opportunities to demonstrate what they know. Bronwen Cowie, Judy Moreland, Alister Jones and Kathrin Otrel-Cass (2008) argue that providing students with multiple and multi-modal assessment opportunities goes some way towards meeting the needs of the diversity of students now in science classroom. Teresa Crawford (2005) provides a detailed description of how providing a student with an opportunity to choose between multiple ways of presenting his work led to his success in demonstrating competence. Nevertheless, providing students with multiple opportunities and a selection of modes to represent what they know does not necessarily remove the representational challenges faced by students or their teachers. To be successful in representing their ideas, students need to be able to identify and engage with the affordances of different tasks and modes of representation (Wyatt-Smith and Cumming 2003). In the case of science, students must manage, sometimes simultaneously, the demands of 'integrating verbal, chemical-symbolic and mathematical meaning systems across genres that depend as much on visual layout as on linguistic syntax or vocabulary meanings for their sense' (Lemke 2001, p. 175). Students need instruction to support the development of the knowledge and skills that they need to be able to select and to use the most apt representation/mode or combination of modes (Newfield et al. 2003). At another level, there is some evidence that teachers target particular students (Tobin and Gallagher 1987). Given the demonstrated benefits of formative feedback, it is important that all students have equitable access to occasions when they are able, and feel willing, to interact with their teacher about their learning.

In classrooms where the student group is diverse, the cultural validity of assessment tasks is a consideration (Lokan et al. 1999). Cultural validity issues extend beyond a concern with language. Students might not only lack familiarity with particular task formats and contexts, but their cultural values, beliefs, experiences and communications styles could influence both their willingness and ability to engage with assessment. For example, Desmond Hung (2009) found that, because of student reticence to ask and answer as part of a cultural norm of respect, students benefited more from written than oral feedback. When teachers work with students from diverse cultures, it is also important that they respect the various world views and understandings that students bring to class whilst they are guiding students to see the relevance and value of scientific ideas, attitudes and values (Aikenhead 2001; Glynn et al. 2008).

Conclusion

Curriculum, pedagogy, assessment, learning and what counts as achievement are inextricably linked and mutually influential. On the basis of evidence of its efficacy, formative assessment/assessment for learning is being advocated as a means of increasing student learning motivation, achievement and agency, which are all important qualities if students are to become active participants in knowledge-rich democratic societies in which science plays an important role. However, assessment in support of learning is still not common practice in science classrooms. The knowledge and skills demands associated with responding to student learning in the moment mean that formative assessment is no easy task for science teachers. The expansion of the goals for science education, to include a concern with developing student conceptual knowledge, student understanding of the nature of science and student appreciation of the role of science in society, only add to this challenge.

Research on formative assessment from within a socio-cultural perspective locates assessment within classroom interaction and directs attention to the active role that students need to play within assessment. When formative assessment is embedded in a classroom, what it means to be a student/learner changes: teacher–student assessment opportunities and relationships are based on power with, rather than power over, students (Gipps 1999). Student intellectual agency is important because this relies on students having multiple and multi-modal opportunities to demonstrate and debate what they know and can do, as well as access to the feedback and resources that they need to move their learning forward. This conception of classrooms and student engagement resonates with science research on classroom discourse, augmentation, multi-modal pedagogies and learning environments that supports the active engagement of a diversity of students. Seen this way, formative assessment provides another tool for helping teachers to reflect on and revise their teaching; this tool has the potential to be the Trojan horse (Black and Wiliam 2006) than opens up new possibilities for teachers and students. This said, a socio-cultural view of assessment raises some questions which have not been fully addressed. These include questions about the appropriate unit of analysis for assessments when learning and knowing are seen as context dependent (situated) and distributed across the resources, routines and people in a particular setting. It leaves moot questions about the appropriate time scale for assessment, including assessment for learning: How might teachers track and support student learning over time and contexts? This question is salient at this time when the goal is to promote the development of students as lifelong learners who have an affiliation with science and the understandings and skills that they need to engage with scientific ideas as part of life in the twenty-first-century. This chapter has set some of the insights and opportunities for researchers and teachers adopting a socio-cultural view of formative assessment and illustrated some of the potential for synergy across fields of research. These are worthy of further investigation.

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Chapter 46
Transfer Skills and Their Case-Based Assessment

Irit Sasson and Yehudit J. Dori

Applying domain knowledge and skills from one domain to new learning situations, recognized in the literature as transfer, is a major educational goal. Empirical studies were conducted to assess transfer knowledge and skills in a variety of instructional environments. There is disagreement in the literature about the definition of transfer, which stems from the fact that transfer has several dimensions (Barnett and Ceci 2002). Moreover, research on transfer is fragmented because of the lack of a holistic view of transfer. Following a review of literature on theoretical aspects and definitions of near and far transfer skills, we introduce a case-based method for assessing transfer skills and describe a study of high school chemistry students' near and far transfer skills. We propose a comprehensive, three-dimensional model of transfer in science education.

Theoretical Background

Transfer Skills

Transfer refers to students' ability to recall knowledge and skills, and to apply them in new learning contexts (Detterman 1993; Gagne 1975; Salomon and Globerson 1987). Erik De Corte (2003) has defined transfer as a broad, productive,

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and supported use of acquired knowledge, skills, and motivations in new contexts and learning tasks. Knowledge and skills that are learned in today's classroom might be utilized in students' unknown future contexts. Therefore, there is a need to provide an education that lasts a lifetime (Halpern and Hakel 2002), with transfer of learning being a major goal of instruction (Lee 1980). The importance of transfer is rooted in both theory and practice. Transfer carries the theories of cross-task correlations and general intelligence. Much of the human and financial investment in education has been justified on the grounds that formal schooling helps to instill general skills that transfer beyond the world of academia and thus help students to become more productive members of society (Barnett and Ceci 2002). Two types of transfer, near and far, are often distinguished (Detterman 1993). Near transfer occurs when the new learning situation differs from a previous one only slightly. Far transfer concerns performing assignments in a new learning situation with different patterns from those to which students are accustomed. Transfer skills include written and oral communications, self-organization, problem-solving, and the ability to work in teams. Robert Sternberg and Peter Frensch (1993) encouraged teaching for transfer as a mode that benefits students the most and forms a bridge between knowledge and practice (Race 1998).

Ference Marton (2006) has characterized transfer as a situation in which the learner, having learned something in one situation, might be able to learn or do something different in other situations, noting differences or similarities. Ross Engle (2006) emphasized the quality of initial learning, engagement with multiple examples, comparison between examples, and formation of generalization as main factors for enhancing transfer. James Greeno (2006) responded to the papers of Ference Marton (2006) and Randi Engle (2006) by suggesting that learning should include discerning aspects of differences and similarities to previous learning in order to form a domain structure. This way of connected knowledge can be important in understanding and fostering learning that transfers productively. Ference Marton's emphasis on sameness and differences in transfer reinforces our adoption of Douglas Detterman's (1993) definition of near and far transfer.

Near transfer is when the new learning situation is sufficiently similar to a previous situation and differs from it only slightly. Far transfer, on the other hand, occurs when students have to perform in a new learning situation with different patterns from those to which they were accustomed.

Definitions and Dimensions of Transfer

The literature on transfer relates to this educational concept in broad terms. Analysis of theoretical articles has led us to classify the various original definitions of transfer skills into three dimensions:

- Task Distance (TD), which refers to the similarity or difference compared with a previous task or assignment

- Interdisciplinarity (I), which refers to contexts, domains, or disciplines
- Thinking skills set (S)

Table 46.1 lists several different definitions and classifications of transfer. The right-most column contains one or more of the three transfer dimensions that apply to each definition. Note that the time dimension is not included in our model, because our view is that transfer can be assessed over time.

Assessment of Transfer

Transfer first appeared in the literature when Judd (1980) discussed the relationship between the learner and the learning environment. Thorndike (cited in Marton 2006 and Subedi 2004) studied transfer nearly a century ago by investigating the similarities between situations.

Measuring transfer is an important way to evaluate educational success (Bransford and Schwartz 1999). Failures to achieve transfer have been reported in the empirical literature (De Corte 2003). Students often fail to link knowledge from previous learning to potentially applicable cases at hand (Bassok and Holyoak 1993; Perkins and Salomon 1988). David Carraher and Analúcia Schliemann (2002) criticized some transfer research for being overly dependent on the perspective of the researcher and on models of expert performance. They suggested investigating how learning is influenced by prior knowledge and experience. John Bransford and Daniel Schwartz (1999) claim that transfer is often difficult to detect and suggest that new theories and measures of transfer should be acquired. John Lobato (2006) argued that researchers' progress in understanding and supporting the generalization of learning has been limited because of methodological and theoretical problems associated with transfer.

Learning Environments and Methods that Foster Students' Transfer

Designing learning environments in order to foster students' transfer of both knowledge and skills is a major goal in education. Erik De Corte (2003) emphasized the relationships between the design of learning environments and students' cognitive outcomes in general and transfer skills in particular. He suggested some principles for the design of powerful teaching and learning environments. Such environments should (a) support constructive learning processes in all students, (b) enhance students' cognitive and motivational self-regulation, (c) include sociocultural supports for learning collaboration, (d) include challenging problems, and (e) enhance students' reflection on learning processes.

Table 46.1 Definitions and dimensions of transfer skills

Definition of transfer skill	Sources	Transfer skill dimension
Near transfer occurs when the new learning situation is quite identical to a previous situation and differs from it only slightly.	Marton (2006), Barnett and Ceci (2002), Perkins and Salomon (1996), and Detterman (1993)	Refers to similarities and differences between learning situations (TD)
Far transfer occurs when learners have to perform in a new learning situation with different patterns from those to which they were accustomed.		
Specific transfer includes transferring the contents of learning to a new situation.	Detterman (1993)	Refers to the knowledge being transferred: context or contents, and skills (I+S)
Nonspecific or *general transfer* occurs when general skills or principles transfer to new situation.		
Negative transfer of learning occurs when learning in one context undermines a related performance in another context.	Perkins and Salomon (1996)	
Positive transfer of learning occurs when learning in one context enhances a related performance in another context.		
Within-task transfer is defined as use of dimensional integration by adding on a novel task from a taught task.	Butterfield and Nelson (1991)	Refers to the role of instruction, comparison, and integration of skills (S)
Across-tasks transfer is defined as use of integration by adding on a task that had not yet been taught.		
Low road transfer occurs in situations that are similar to previous practice. It often characterized by a reflexive response in the transfer situation and little ability to symbolize verbally or otherwise the strategy or principle being applied.	Perkins and Salomon (1996)	Refers to similarities and differences between learning situations, skills, variety of contexts, domains, or disciplines (TD + I + S)
High road transfer includes application of ideas and principles in different domains. It involves deliberate abstractions from one context and application to another, leading to a deliberate response and ability to describe the strategy or principle being applied.		

(continued)

Table 46.1 (continued)

Definition of transfer skill	Sources	Transfer skill dimension
Specific and short-term learning – retention: Cognitive structure variables refer to the organizational properties of the immediate and relevant concepts that affect the learning and retention of relatively small units of related new subject matter. *General and long-term learning*: Cognitive-structure variables refer to significant properties of the learner's total knowledge that influence his future academic performance in the same area of knowledge.	Ausubel et al. (1978)	Refers to the performance level in the same subject matter (I)
Vertical transfer requires mastering a certain level of skills in order to learn higher-level skills. *Lateral transfer* requires generalization of learning themes without necessarily learning new skills.	Gagne (1975)	Refers to the learning hierarchy and thinking skills (S+I)

The effect of problem-solving-based learning on transfer of knowledge and skills was intensively explored in medical education (Adams et al. 2003; Norman and Schmidt 1992; Young et al. 1998). In science education, learning environments that incorporate an inquiry-based approach or case studies are recognized as fostering students' transfer skills (Lee and Thompson 1997; Lohman 2002; Muthukrishna and Borkowski 1995; Sasson and Dori 2006). Julia Schuh et al. (2006) investigated the effect of dynamic visualisations on problem-solving skills in transfer assignments. They found a significant effect of the dynamic visualization for both near and far transfer skills.

Case Studies

Case studies are narrative descriptions or stories that can motivate learning (Norris et al. 2005). Case studies have been viewed as "windows into science classrooms" that contribute to teachers' professional development (Tobin et al. 1990). Thomas Koballa and Deborah Tippins (2000) noted that case studies can serve as a tool for professional preparation and development, as a discipline-based teaching method, as a means for facilitating critical thinking and exploring dilemmas, and as an assessment tool. Similar to case studies, Patricia Heller and colleagues (1992) and Patricia Heller and Mark Hollabaugh (1992) defined a short story as a context-rich problem, the statement of which does not always identify the unknown variables in a straightforward manner, often requiring assumptions to be made. They found that students were more likely to use an effective problem-solving strategy when given context-rich problems than when given standard textbook problems.

The case study method enabled the evaluation of students' and teachers' higher-order thinking skills (Dori et al. 2003a, b; Wassermann 1994). In previous papers (Dori et al. 2004; Dori and Sasson 2008; Kaberman and Dori 2009a), we presented the case study method in a computerized environment and its contribution to fostering question posing, inquiry, modeling, and graphing skills. In this chapter, we discuss the use of case studies as a tool for assessing transfer skills. The case-based method is demonstrated in a study conducted in the Case-based Computerized Laboratory (CCL) learning environment described below.

Case-Based Computerized Laboratory Learning Environment

The CCL environment integrates computerized experiments with emphasis on scientific inquiry and comprehension of case studies. Students' activities in small groups include also collecting sensor-generated data, constructing graphs in real time, and interpreting results (Sasson and Dori 2008). Each one of the five CCL units includes three stages:

1. Theory: a theoretical inquiry, which includes reading a related case study and carrying out assignments aimed at developing higher-order thinking skills
2. Experimentation: a laboratory guided inquiry in which students conduct a computerized experiment and perform data analysis with an emphasis on chemical understanding
3. Investigation: further independent inquiry in which students are asked to conduct a new open-ended experiment and suggest ideas for further investigation.

Adopting the constructivist approach, the CCL learning environment is designed to foster students' active learning, interest, and social interactions. Unlike the specific thinking skills (question posing, inquiry, graphing, and modeling) that are specifically targeted by the CCL learning unit, transfer was not explicitly taught. However, the interdisciplinary nature of the case studies and the variety of skills required led us to believe that students might be able to carry out transfer.

The laboratory activities assume previous chemical knowledge that students gained in theory-based sessions in a previous year (11th grade). This knowledge includes familiarity with four levels of chemistry understanding: (a) the symbol level – formulae, equations, and graphs; (b) the macroscopic level – the observable or tangible phenomena; (c) the microscopic level – explanations using molecules, ions, atomic or subatomic particles (Gabel and Bunce 1994; Johnstone 1991; Nakhleh and Krajcik 1994); and (d) the process level – the way in which substances interact with each other (Dori et al. 2003a; Dori and Hameiri 2003). The process level often embodies one or more other levels of chemistry understanding (Dori and Sasson 2008; Kaberman and Dori 2009b).

In the CCL learning environment, near transfer was assessed by the ability of a student to apply previous knowledge to a new but fairly similar assignment and to analyze it using the chemistry understanding levels. Far transfer required that the student demonstrates the ability to: (a) perform an assignment that is sufficiently different than the ones taught in the CCL learning unit (TD), (b) establish links between chemistry and other science disciplines (I), and (c) integrate two or more skills.

Case-Based Assessment of Transfer Skills

The study included two stages. In the first stage, we interviewed seven CCL students following their performance of case-based assignments that included near and far transfer. Students were asked to respond to the assignments using the think-aloud method and to reflect on their thinking processes. In the second stage, 670 grade 12 chemistry honours students completed pretest and posttest case-based questionnaires.

Research Description and Tools

Table 46.2 presents the research objective, participants, tools, and the data analysis method. The near transfer assignment for the case study in Fig. 46.1 was the following:

> Both Dioxin and BaI_2 are solids with melting temperatures of 295°C and 740°C, respectively. Describe and compare the melting processes of these two substances.

This is a near transfer assignment because it requires knowledge and application of previous chemical understanding of intermolecular bonding of both ionic crystals and molecular materials. This subject was studied theoretically a year earlier as part of the chemical structure and bonding topic. We defined it as a near transfer assignment because it is similar to one or more assignments from the students' earlier learning (Task Distance – TD is short) and the subject matter is chemistry (No Interdisciplinarity – I).

The far transfer assignment included the following two questions, which also referred to the case study in Fig. 46.1.

> Natural processes in fruits might produce toxic substances. A specific fungus causes the production of Patuline, a dangerous toxin in apples. This toxin is transferred from the apples to apple juice.
>
> (a) Describe the special characteristics of the Patuline compound, which enables it to be transferred from the fruit to the processed juice.
> (b) Suggest a suitable technique for reducing this problem. Refer to both advantages and disadvantages of your solution.

Table 46.2 Description of two stages of research

Research objective	Participants	Research tools	Data analysis
Investigate the use of case studies as a tool for assessing transfer skills	7 students, chosen to represent both high and low academic levels	Interviews	Inductive analysis
	670 12th grade chemistry honours from 24 high schools	Case-based questionnaires	I. Content and descriptive, qualitative analysis II. Statistical analysis

Household Garbage Combustion

Combustion is a common method for treatment of household garbage (waste). This method was found efficient for reducing garbage volume and transportation distances. Experts have concerns regarding the emission of Dioxin to the air during this combustion process. Dioxin ($C_{12}H_4O_2Cl_4$), a chloro-organic compound, is the most toxic substance to humans. Its toxicity is 70 times higher than Cyanide. During the Vietnam War, USA forces used Dioxin for chemical warfare. Several years later, high concentrations of Dioxin were found in river fish nearby.

Fig. 46.1 The opening paragraph of the "household garbage" case study

This far transfer assignment calls for comprehension of the problem at several levels of chemical understanding and for application of science disciplines other than chemistry (I exists). This assignment requires far transfer also because students did not practice it as part of the CCL unit (TD is far) and it involves several skills – comprehension, application, and synthesis (S).

The interviews, which were conducted after the seven students had read the case study and responded to the assignments, involved the following questions:

1. What are the differences (if any) between the assignments?
2. Describe your thinking process while performing these assignments.

Each interview lasted about 30 min. All the audiotaped interviews were transcribed and content analysis was carried out after identifying key categories. Additional case study titled *Trees cause air pollution – Is this possible?* (Sasson and Dori 2006; Kaberman and Dori 2009a) served as the basis for the interviews.

Analysis of Students' Interviews

Students perceived the near transfer assignment as being relatively simple and requiring previous knowledge in chemistry. Referring to a near transfer assignment (*in* response to Q. 1), student A said: "This is a knowledge question. Subjects that I learned during the chemistry lessons might help me to reply correctly."

The far transfer assignments were perceived as unfamiliar and requiring application of knowledge from other science domains. For example, student S said: "It has a connection to biology. I can relate the chemical aspects in the case study to life." Student G said: "The question requires thinking. I can't reply to it automatically. I need to apply my knowledge in addition to understanding." Some of the students felt uncertainty regarding the far transfer assignment, as expressed by student A: "I always had the feeling that I'm missing something here." When the researcher insisted that the students reflect on their thinking processes or solution stages, student D said: "My first thought in responding to this [Far transfer] question was the connection to the receptors in the animal smell system, but then I thought that, if this is a chemical question, I must concentrate on the chemical aspects. If you want me to relate the answer to biological aspects, you have to include this instruction in the question."

The interview results have strengthened our confidence in the design of the near and the far transfer assignments. While exposing their thinking processes, students expressed their need to apply chemical understanding in the near transfer assignment. In the far transfer assignment, students expressed a need to refer to other science domains in addition to chemical understanding. Students regarded the far transfer assignment as more difficult than the near transfer one.

The analysis revealed differences between high-academic and low-academic students' performance in near and far transfer assignments. Differences between students at different academic levels stemmed from their different abilities to identify the problem features, similarity to a previously known problem or pattern, and application of interdisciplinary knowledge. Table 46.3 presents these characteristics of students' thinking processes while performing the transfer assignments.

Findings from Case-Based Questionnaires

Pretest and posttest case-based questionnaires were designed to assess a host of thinking skills, including question posing, inquiry, modeling and graphing (Dori and Sasson 2008; Kaberman and Dori 2009a), and near and far transfer (Sasson and Dori 2006). The questionnaires included a variety of assignments for investigating these thinking skills. All the assignments, which aimed at assessing the entire set of examined thinking skills, were incorporated into the calculation of students' total scores for the pretest questionnaire. This pretest total score was the basis for dividing the 670 students into high, intermediate, and low academic levels.

We analyzed the responses of all students to the near and far transfer assignments using special rubrics that we had developed. Each student's response was scored and normalized on a 0–100 scale. Table 46.4 presents examples of students' responses to the near transfer assignment. Criteria for assessing the near transfer skill were the number of chemistry understanding levels that students used and the quality of their explanations.

Table 46.3 Characteristics of students' thinking processes while undertaking assignments

	Students' responses		
Feature	High academic level students	Low academic level students	Authors' interpretation
Identification of the assignment's requirements and difficulties	"The first [near transfer] assignment has a familiar pattern, which I recognize from our practice in class. The second [far transfer] assignment has an unfamiliar pattern. It requires more thinking beyond the chemical knowledge."	"The second question [far transfer] is more difficult because I don't know what the characteristics are."	High academic students quickly identify the assignment requirements. Low academic level students experience difficulties explaining the differences between near and far transfer assignments.
Fitting previous chemical knowledge to the new situation	"First, I understood the role of the compound in the communication between animal species. Then, I tried to fit my chemical knowledge regarding the isoprene compound to this role."	"I don't know what can help me to perform this assignment [far transfer]. I need additional information related to chemistry."	High academic students connect knowledge from various sources. Low academic level students experience difficulties in connecting the assignment to their previous knowledge.
Dependence only on the case study text vs. using additional information, not found in the case study	"The second [far transfer] assignment requires, in addition to the information in the text, more information from my experience and knowledge."	"In contrast to the first assignment, the second [far transfer] assignment requires reading the text again."	High academic students use previous knowledge that is not mentioned in the text. Low academic students have dependence on the provided text.
Interdisciplinary approach: Invoking other disciplines relevant to the problem at hand	"The assignment has biological aspects. It is important to establish contacts between different domains."	No reference to this type of thinking process was mentioned.	High academic students identify relations with other disciplines. Low academic students have difficulties in relating the application to other disciplines.

Table 46.4 Examples of students' responses to the near transfer assignment

Example	Student response	Assessment features
Example 1: Adequate response	"$BaI_{2(s)} \rightarrow Ba^{+2}_{(l)} + 2I^{-}_{(l)}$ $C_{12}H_4O_2Cl_{4(s)} \rightarrow C_{12}H_4O_2Cl_{4(l)}$ Dioxin is a molecular substance with Van Der Vaals interactions between its molecules and BaI_2 is an ionic crystal with high electricity attraction between its ions. Because the attraction between particles in the ionic crystal is higher than in the molecular substance, the melting temperature of BaI_2 is higher. The BaI_2 liquid contains free ions and therefore conducts electricity while. Liquid Dioxin doesn't conduct electricity."	• Correct reference to characteristics of substances • Correct explanation using three chemistry understanding levels (macroscopic, microscopic, and symbolic) • Connecting between these levels
Example 2: Insufficient response	"BaI_2 is an ionic crystal (compound based on metal and nonmetal substances) and therefore has a stronger chemical connection and higher melting temperature than Dioxin which is a molecular substance."	• Correct identification of the types of substances • Reference to the macroscopic level • Insufficient reference to the microscopic and symbol levels

Table 46.5 presents three examples of students' responses to the far transfer assignment. Criteria for assessing the far transfer skill were the number of chemistry understanding levels, the quality of the explanations, and the number of other science and engineering disciplines –biology, physics, environment, industry, and economics – that were involved in the solution that the student suggested. (The rubric appears in Appendix.)

Calculation of the discipline content score was based on the number of correct science or other domains included in the response. Science domains were chemistry, biology, and physics while other domains were engineering, economics, and health. A student's total far transfer score was calculated as follows:

$$\begin{aligned}\text{Far Transfer Score} = {} & \text{chemistry understanding levels score} \\ & + \text{chemistry understanding levels connection score} \\ & + \text{disciplinary }\left(\text{or interdisciplinary}\right)\text{ content score.}\end{aligned}$$

We consider that the assessment process of near transfer assignments would be familiar to most of the science educators; therefore, in this chapter we focus on the use of case studies as an assessment tool for the far transfer skill. Figure 46.2 represents the frequency of the three levels of chemical understanding and the number of science disciplines included in the students' responses. In the pretest questionnaire, the majority of the students used the macroscopic level to describe the compound characteristics, while microscopic-based and process-based explanations were rare. However, in the posttest questionnaire, there was an increase of about 2.5 times

Table 46.5 Examples of students' responses to far transfer assignment

Example	Students' response	Assessment features
Example 1: Excellent response	"a) I expect the toxin to be soluble in water, which means that there are hydrogen bonds between its molecules. In addition, it has to be soluble in the cells plasma as well, and therefore there are Van Der Vaals interactions between its molecules. I expect it to be stable in a wide range of conditions. b) I suggest a special photochemical process which might be inexpensive and efficient. Research is needed regarding the effect of this process on other aspects or substances in the juice."	• Correct explanation using the macroscopic, micro-scopic and process levels • Reference to chemical and biological aspects of the characteristics of the compound • Connect between two levels of chemical understanding
Example 2: Adequate response	"a) I expect the toxin to be stable in a wide range of temperatures. In addition, its structure has to fit transferring through the fruit cells walls. It's important that the toxin will not react with any industrial additives or preservatives that are added to the juice. b) I suggest adding a chemical substance that harms the fungus. Finding such substance is an expensive process and this substance might change the taste of the juice."	• Correct explanation using the macroscopic level and partially the microscopic level • Reference to chemical, biological, industrial, and economical aspects of the characteristics of the compound
Example 3: Partial response	"a) I expect the toxin to be stable and soluble in water. b) I suggest heating the juice until the toxin decomposes. This is a simple and inexpensive method, but it might affect the taste of the juice."	• Reference only to the macroscopic level • Reference to chemical, industrial and economic aspects of the characteris-tics of the compound

compared with the pretest questionnaire in the microscopic and process levels of chemistry understanding. The frequency of using the microscopic level increased from 7% to 18% and of using the process level increased from 16% to 43%.

The dominant discipline that students mentioned in their pretest questionnaire was chemistry (50%), while biology and physics together accounted for 25%. In the posttest questionnaire, the use of chemistry increased to 64%, while that of the two other disciplines increased to 41%. This increase represents the progress students made in transferring knowledge from chemistry to other science or engineering domains. Students improved their near and far transfer skills during their chemistry course in 12th grade.

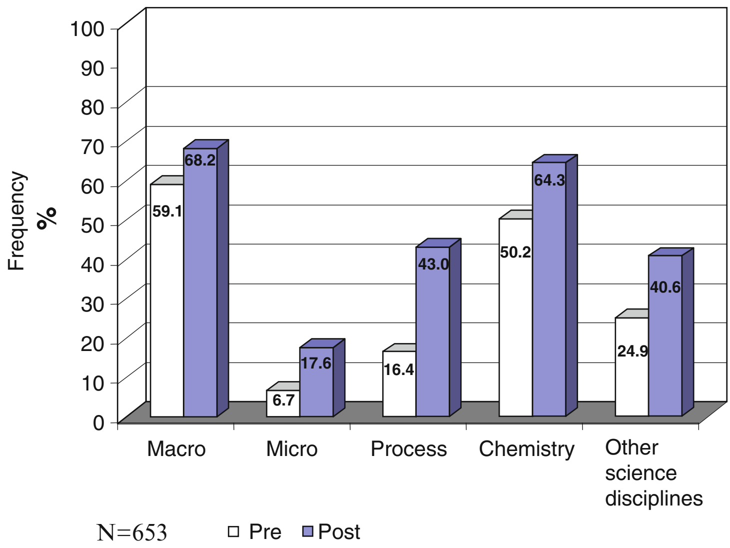

Fig. 46.2 Frequency of using chemistry understanding levels and science disciplines in the far transfer assignments

Table 46.6 Students' net gain scores for near transfer skills for two academic levels

Research group	Academic level	*n*	Net gain	SE	*t*	Effect size
Experimental group	Low	74	26.6	4.1	6.40*	0.74
	High	154	23.4	2.7	8.55*	0.68

* $p < 0.001$

Net Gain in Transfer Skill

Net gain scores, indicating students' improvement in near and far transfer skills, were calculated for each student as the difference between her/his pretest and post-test scores. Tables 46.6 and 46.7 present students' net gain scores in near and far transfer skills, respectively, sorted by academic level. These tables show that the students significantly improved their near and far transfer skills.

Discussion

Thinking skills are necessary tools in a society characterized by rapid changes. Transfer is a bona fide higher-order thinking skill that reflects a student's ability to apply taught skills and knowledge to seemingly unrelated topics or disciplines. Educational institutions and workplaces are increasingly concerned with the question of what are the essential professional transferable skills that are needed (Dall'Alba and Sandberg 2006). In this chapter, we focused on assessing transfer skills by case studies.

Table 46.7 Students' net gain scores in far transfer skill for two academic levels

Research group	Academic level	*n*	Net gain	SE	*t*	Effect size
Experimental group	Low	79	35.0	3.9	8.9*	1.00
	High	175	28.0	2.1	12.8*	0.97

$* p < 0.001$

The findings of our case-based transfer study are in line with the high road transfer of David Perkins and Gavriel Salomon (1988), who claimed that application of ideas and principles in different domains involves reflective thought in abstracting from one context and seeking connections with other domains. Students perceived far transfer assignments as more complex than near transfer ones because, in addition to chemical understanding, the former required the ability to apply knowledge in different science disciplines. Finding a solution to a far transfer assignment is an unknown process that can cause some students to feel insecure.

Heller et al. (1992), and Heller and Hollabaugh (1992) found that cooperative group learning improved problem-solving performance. In well-functioning cooperative groups, students can share conceptual and procedural knowledge and exchange scientific arguments and justifications among themselves. Consequently, we assume that interactions between students of high and low academic levels within the small investigation groups in the CCL learning environment might have contributed to the exchange of knowledge processes and the development of the transfer abilities of both academic level students. Indeed, both students of low and high academic levels significantly improved their near and far transfer skills scores on the posttest of the case-based questionnaire compared with the pretest. These significant results were repeated in each of the 2 research years, further validating the positive effect of the CCL environment on students' learning outcomes. Based on a meta-analysis study, Margaret Lohman (2002) claimed that the case study approach is an educational tool which fosters near transfer of content knowledge and skills. Our results, however, indicate a positive effect on far transfer as well. This is in line with the results obtained by Mi Ok Lee and Ann Thompson (1997), who found that guided instruction in Logo led to increased comprehension in both near and far transfer tasks. Transfer was spontaneous and fostered by the learning environment rather than by routine and explicit instructions.

One possible explanation for the success in transferring chemical knowledge and skills to other domains could be the exposure of students to a variety of case studies in which the subject matter was integrated with principles from other science disciplines. This explanation is in line with other researchers' claim that generalizing ideas and principles in a variety of contexts might foster transfer skills (Engle 2006; Perkins and Salomon 1998). Because students did not receive explicit instruction for transfer, we assume that the interdisciplinary nature of the case studies and the practical aspects of the laboratories fostered far transfer. This assumption is based on the work of Bob Campbell and Fred Lubben (2000), who suggested that meaningful learning might occur when relevant issues are well connected into classroom learning. The assumption that the interdisciplinary nature of the cases contributes positively to far transfer draws also on Hee-Sun Lee and Nancy Songer (2003). They claimed that real-world situations that were matched to students' academic level created a good opportunity for developing their comprehension and knowledge applications.

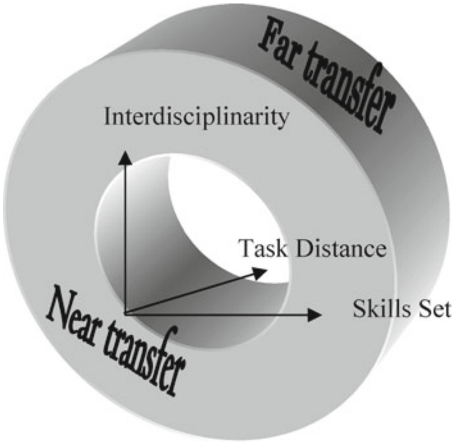

Fig. 46.3 Characterisations of the 3D transfer skills framework: Near vs. far transfer

Based on a critical review of the literature on transfer, we presented a three-dimensional scheme of transfer, with the dimensions being task distance, interdisciplinarity, and skills set. Task distance, proposed by Douglas Detterman (1993) and Ference Marton (2006), is the task's or assignment's similarity on one side of the spectrum and the degree by which they differ on the other side of the spectrum. Interdisciplinarity, also proposed by Douglas Detterman (1993), involves the integration of knowledge of more than one discipline or subdiscipline in order to gain insights into and solution for new problems. Skills set, suggested by Robert Gagne (1975), includes mental abilities and performances that are developed or evolved via learning processes, training, or experience.

Each dimension in its own right encompasses a complex spectrum of concepts. The interdisciplinarity dimension starts with a confined subdiscipline and passes through entire discipline all the way to the integration of disciplines from increasingly disparate domains. The skills set ranges from lower-level thinking skills, such as memorizing and algorithmic skills, to higher-order thinking skills, such as question posing, inquiry, graphing, and critical thinking. Finally, the task distance dimension ranges from complete sameness or similarity incrementally to total disparity or unlikeness.

Based on these insights, we suggest a theoretical framework in which transfer is characterized by the three dimensions and for which the learning situation changes from near to far transfer as presented in Fig. 46.3.

Near transfer occurs when the new learning situation requires application of a relatively small set of skills, revolves around the same discipline content, and uses features that are similar to previous learning situations to which the student was exposed. In contrast, far transfer occurs when a student has to perform in a new and different learning situation that requires application of skills and knowledge from one or more disciplines other than the one in which the learning originally took place. The space that spans the combination of these three complex dimensions gives rise to a wealth of characteristics.

The way in which we measure transfer affects the success or failure of transfer (Bransford and Schwartz 1999; Broudy 1997; Carraher and Schliemann 2002). Our research emphasizes the use of the case-based method for evaluating transfer skills. We presented case-based rubrics for assessing students' transfer skills, which respond to the call of Joanne Lobato (2006) and Susan Barnett and Stephen Ceci (2002) for specifying the various dimensions for determining whether and when transfer occurs.

Dealing with case studies and manipulating data in various representations during learning in the CCL environment prepared students to apply previous chemical understanding in a new case-based assignment. The theoretical framework of the three dimensions of transfer integrates previous researchers' ideas in order to respond to the educational community's needs. The way in which we measure transfer affects the results and determines the success or failure of transfer (Sasson and Dori 2006; Carraher and Schliemann 2002). We recommend that developers of educational programs adjust their transfer assignments according to this three-dimensional framework in order to foster students' near and far transfer skills, and that researchers use this model in assessing transfer studies.

Appendix

Rubric for assessing students' far transfer skill

	Applying chemical understanding levels			Chemistry levels' relationship	Number of correct and relevant characteristics			
Score	Macroscopic level	Microscopic level	Process level		Chemistry	Biology	Physics	Other
0	No use of the macro level or a wrong macro-level explanation	No use of the micro level or a wrong micro-level explanation	No use of the process level or a wrong process-level explanation	No relationship between chemistry understanding levels				
1	Use of one correct characteristic in the macro level	Use of one correct characteristic in the micro level	Use of one correct characteristic in the process level	Partial relationship between chemistry understanding levels				
2	Use of at least two correct characteristics in the macro level	Use of at least two correct characteristics in the micro level	Use of at least two correct characteristics in the process level	Correct relationship between chemistry understanding levels				

All the rubrics were validated by five chemistry educational experts. These five experts also graded 10% of all the students' responses, achieving 90% inter-raters reliability. As a result of this content analysis process, each student's response was scored and normalized

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Chapter 47
Competence in Science Education

Alexander Kauertz, Knut Neumann, and Hendrik Haertig

For more than 50 years, the idea of competence has been discussed in science education and psychology to describe different kinds of capability to master a certain domain (Winterton et al. 2005). It can be used to describe the outcome of school education (Hartig et al. 2008) – such variables include emotional, volitional, cognitive aspects, required skills, abilities, and attitudes (Weinert 2001). However, it is a difficult concept to grasp as it can be investigated from many perspectives (Csapó 2004). Therefore, to come to a measurable construct we limit our view on competence to a cognitive perspective, as many researchers in this field do (Hartig et al. 2008), and leave out motivational aspects which were originally stressed by Robert White (1959).

Theoretical Perspectives on Competence

Science competence is understood as the underlying cause of successful or unsuccessful performance (Chomsky 1965), respectively, in the domain of science (Connell et al. 2003). For example, Dominique Rychen and Laura Salganik (2003) describe key competencies for future success in society. Willis Overton (1985) shows that the

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relation of competence and performance is influenced by many other variables of the situation and the person (cf. Bandura 1990). For example, the choice of mental models (Bao and Redish 2006) and argument (Zimmermann 2005) is dependent on the situation. The performance in tests is dependent, for example, on the time or the choice of items (Kalyuga 2006).

To increase the likelihood of a successful performance through teaching is an underlying idea in education (Csapó 1999). Since competence influences performance, many fields of science education are related to competence (Adey et al. 2007). In the following, we will outline fields related to competence, and how this contributes to the idea of applying structured knowledge (Albert 1994). The aim is to develop a model of competence (cf. Pellegrino et al. 2001) by linking intelligence, problem solving, and knowledge (Glaser 1983). Csapó describes a person's ability to perform successfully in terms of three aspects (Csapó 2004): the cognitive aspect, the content aspect, and the literacy aspect as "the broadly applicable and social valuable knowledge" (Csapó 2004, p. 35). We will use these aspects to structure our discussion of the different fields, as it implements the idea of competence as a mixture of general and specific abilities and knowledge (Winterton et al. 2005).

Cognitive Aspect

Intelligence is a parameter summarizing general cognitive abilities and providing a measure for them (Lauren Resnick 1976). It is thought to be more or less independent from domain and content (Adey et al. 2007). However, David McClelland (1973) shows that intelligence has only limited importance in describing successful performance in a specific domain. He suggests that a theory of competence would result in a list of activities used by successfully performing individuals (McClelland 1973).

Such a theory could be the taxonomy of Benjamin Bloom (1956). It is one example of models that rank abilities by cognitive processes with the transfer process as the most demanding one (Klauer 1989). It was further elaborated by Lorin Anderson and David Krathwohl (2001), who rank activities by analyzing which abilities are needed to perform successfully in the respective activities.

Another option would be the expert and novice paradigm. Experts can be differentiated from novices by the problem-solving strategies they have at hand (Boshuizen et al. 2004). That is, these strategies are part of their competence (Sternberg and Grigorenko 2003). With cognitive load theory (Sweller 1994) it can be argued that the limited capacity of the working memory requires an elaborated knowledge structure to solve complex problems. Problem solving as a cognitive task, therefore, can be discussed under the perspective of general strategies (e.g., Dossey et al. 2004) as well as under a science-specific perspective considering science knowledge (Klahr and Dunbar 1988). In a nutshell, problem-solving tasks require a general and science-specific competence.

Content Aspect

In order to measure content-specific abilities, first of all the related content has to be described and structured (Albert 1994). School science content typically includes knowledge, typical procedures in science like modeling and experiments, or argumentation, and meta-knowledge about nature of science and scientific inquiry. Curricula and educational standards are the basis for the selection of content and the description of desired competencies. And despite every nation defining its own curriculum, there is an overlap in the choice of content and competencies (Parker et al. 1999).

The knowledge base of science is represented by mental models based on scientific theories and models that should be learned by students (Gentner and Stevens 1983). The structure of those mental models is described for many concepts in science, for example, for matter and its transformation (Andersson 1990), for energy (Lijnse 1990), or for mechanical waves (Wittman et al. 1999). These mental models are based on concepts whereby students' concepts might differ from scientific concepts of the same issue (Carmichael et al. 1990). Concepts and mental models are structured by the big ideas of science which are often described as basic concepts in science, for example, energy (Dawson-Tunik 2006) and matter (Liu and Lesniak 2006).

The role of experiments for school science is well investigated and widely discussed in science education (Lunetta 1998). Experiments are part of scientific working and therefore embedded into scientific inquiry which is seen as essential for learning science (Minstrell and van Zee 2000). Experiments are used for argumentation and reasoning in science (Zimmermann 2005) fostering communication skills (Saab et al. 2007) and logical reasoning (Nunes et al. 2007). In this context analogies are used for modeling phenomena (Pauen and Wilkening 1997) or for illustrating certain concepts, for example, force (Palmer 1997).

Meta-knowledge, which is beliefs and knowledge about knowledge in a certain domain (Bromme 2005), is also part of science content in school (cf. American Association for Advancement in Science (AAAS) 1993; National Research Council (NRC) 1996). Meta-knowledge is described as the nature of science and, for example, the role of experiments in the scientific discovery process rather than the "how-to" of experiments. Nature of science allows for judging scientific findings and is useful for participation in adult life (Lederman et al. 2002).

Literacy Aspect

The Programme for International Students Assessment (PISA) refers to the concept of scientific literacy as an internationally consensual aim of education (Organisation for Economic Co-operation and Development (OECD) 1999). Scientific literacy is understood as a set of competences to be acquired as a result of education (Bybee 1997) and is substantially different from a scientist's competence (OECD 1999). As the main difference, competence in the notion of scientific literacy requires detaching the content from the context. Although content is learned in specific situations, the ability to transfer is the main aspect of competence (Csapó 1999); that is, the ability to apply strategies in various contexts (Garner 1990) and to use mental models in different settings (Lijnse 1990). However, this is sometimes not even achieved by adults (Murray et al. 2005). This is due to the difficulty in transferring between domains (Roth 1979). Still, competence as the ability to detach science content from situations is seen as important for full participation in adult life (Connell et al. 2003).

In a more formal way and closer to the original meaning of Csapó's literacy aspect, an individual's literacy can be described by complexity. While complexity can be used with a rather qualitative meaning to distinguish between higher or lower cognitive processes (Kail and Pellegrino 1989) or reasoning and acting (Zelazo and Frye 1998), complexity can also be used to describe a hierarchy of structures within a system (Commons 2007). Since scientific knowledge could be seen as such a system with an inner structure (Gagné and White 1978), complexity can be used to rank solving processes (Williams and Clark 1997), compare different knowledge structures (Nicolis and Prigogine 1987), or describe different levels of the knowledge structure (Kauertz and Fischer 2006). The structure of knowledge is made up of elements, for example, scientific facts which are linked together by functional relations (Novak 1998). This structure represents basic concepts in science such as energy and system. Because basic concepts include a large number of scientific facts and relations (cf. Resnick and Ford 1981), an individual's literacy is represented by the level of complexity on which the person can deal with the particular basic concepts.

Definition of Competence

The notion of competence as a developable capacity to detach science-specific cognitive processes and knowledge from one situation and apply it to scientific problems in a social setting is described by the Organization for Economic Cooperation and Development (OECD) in terms of scientific literacy:

> Scientific literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity. (OECD 1999, p. 60)

This definition embraces all considerations described earlier and names possible indicators, such as uses knowledge, identifies questions, draws conclusions, and so on, to identify competence by large-scale assessment.

A Measurement Perspective on Competence

Competence as a multifacet variable (Csapó 2004) makes it necessary to define an inner structure of competence (Mislevy et al. 2002). This structure hypothesizes differences between specifications of competence which are theoretically caused by different content, for example, basic concepts, different cognitive activities, and different levels of competence or literacy. The structure can be illustrated by a list of abilities or by a grid; whereas in every cell of the grid specific abilities, skills, and so on are listed, classified by the assumed difference between those activities. Such a grid is not necessarily limited to two dimensions but could also have three dimensions, which would mean a cube, or even more than three dimensions. Since the lists of activities in each cell might be too long or unclosed, the cells could be described by the dimensions. Such dimensions could be the content as the first dimension, whereas any basic concepts make up one row, and as second dimension cognitive activities, with, for example, applying and transfer making up the columns. Each cell is then defined by a basic concept and a cognitive activity, for example, energy and applying. In this cell any ability would be registered that requires the application of the energy concept. Using this grid, the competence is structured in a competence model. The link between the competence model and the items of the test is established by task analysis (Jonassen et al. 1999). As a result of task analysis, each item can fit in one cell of the grid that represents the competence model.

Competence Models

Those models can be post hoc (e.g., OECD 1999, 2001) or a priori (e.g., Neumann et al. 2007) defined models. From a theoretical perspective, the a priori defined models are more valuable (Wilson 2005) since they are empirically testified, while post hoc models are informative for identifying possible critical elements of tasks (e.g., OECD 1999, 2001) but could fail to be reproduced in the next test (Klieme 2000). A sound a priori model as a basis for the test helps to validate its results, as the example of the force concept inventory illustrates (Hestenes and Halloun 2005).

The competence model for the PISA study was made up of two dimensions: scientific processes and content in an area of application. The dimension of processes contained five different processes; for the scientific concepts 13 major scientific themes with 13 areas of application were chosen. Each theme was combined with one area of application. Every cell in this grid (see Fig. 47.1) was described, for example, "[r]ecognising scientifically investigable questions using knowledge of human biology applied in the area of science in life and health" (OECD 1999, p. 66).

Validity of Competence Measurement

Multidimensionality of most competence models makes it difficult to prove their validity. Different kinds of validity need to be considered (Wilson 2005): validity concerning the assumed inner structure, that is, there are as many different

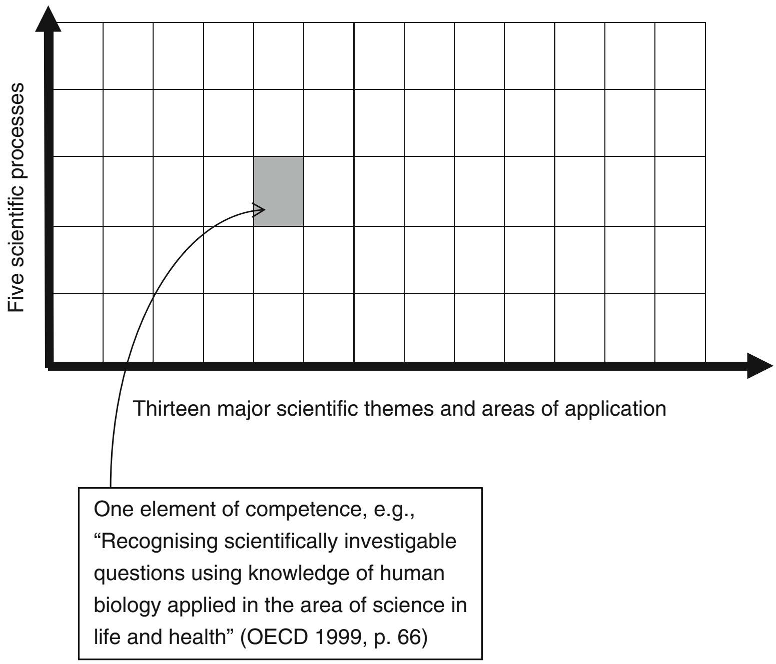

Fig. 47.1 The PISA competence model

dimensions as considered in the a priori model (Hestenes and Halloun 2005); and validity concerning the goal of the assessment, that is, the test measures competence comparable to the PISA tests (cf. Pellegrino et al. 2001). Usually those questions are already considered during test development by the underlying model (Harmon et al. 1997) and tested with the empirical data by comparing the empirical structure with the theoretical structure (e.g., Acton et al. 1994). While competence models have a complex structure, and competence and performance are merely linked by a certain probability moderated by many random influences (e.g., the context; Bao and Redish 2006), a large number of test items and large sample sizes are needed.

Since large-scale competence assessment needs many items, sophisticated statistical procedures like the item-response theory (IRT) are required (cf. OECD 2001). The IRT allows for computing a student's probability for solving items of a certain difficulty and therefore combines the values of student competence and item difficulty on the same scale (van der Linden and Hambleton 1996). Then one item could illustrate the competence of all students with a score equivalent or below the value of the item. Therefore, the relation between items and students can be scrutinized and the underlying structure of the item sample (which in fact is the competence model) and student sample characteristics (which could include gender, age, social background, and so on) can be investigated (cf. Rost 1990).

Relevance of Results from Large-Scale Competence Tests

The relation between competence models and teaching is rather vague. Although competence measurement focuses on the results of learning, the underlying model cannot tell the teacher how to promote learning in the learning group. The model is rather a structure for reachable learning goals. More often, the results of large-scale-competence assessments cannot be related to individuals or even classes since the individuals' measurement errors are out of scale.

Therefore, competence measurement is more informative for educational administration considering the complete educational system (e.g., OECD 1999, 2001). For example, in Germany the results of the Programme for International Student Assessment (PISA) led to a major change in the educational system and the establishment of national education standards (KMK 2004). By comparing nations based on the competence of their students the further development of the economy should be ensured (OECD 1999), and social chances become comparable and can be ensured as well (Millar 2004).

Empirically testified competence models can also inform curriculum development (Driver et al. 1994). Competence models could be a reference point to compare curricula (Kumar and Berlin 1998) and cut them down to relevant aspects, or to develop international curricula (Parker et al. 1999).

Future Research Perspectives on Competence

Because the results of large-scale assessments could not inform teachers about the individual's developmental competence level, an individual diagnostic tool for teachers and researchers is needed (Hartig et al. 2008). This would require more detailed models taking different methods of development into account.

The performance in social settings and competence needs to be investigated as a matter of validity. As different studies showed (Lijnse 1990; Rychen and Salganik 2003), the context strongly influences the relation between performance and competence. One aspect could be a linkage between science competence in school and later vocational competence (Rothwell and Lindholm 1999). Since competence in terms of scientific literacy is meant to allow successful participation in society (OECD 1999, 2001) and this seems not to be sufficiently reached (cf. Murray et al. 2005), the long-run effect of increasing competence is worthy of investigation.

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Chapter 48
Trends in US Government-Funded Multisite K—12 Science Program Evaluation*

Frances Lawrenz and Christopher David Desjardins

The importance of science education in the USA's economic and security interests has been highlighted in a number of national reports. A recent report from the US National Academies cited the significance of science education in maintaining the USA's competitive edge in the world economy (2007). The National Science Board (2007) addressed a declivity in the career choice of engineering as well as a general weakness in the K—12 science, technology, engineering, and mathematics (STEM) curriculum, citing that engineering is the key to an innovative, technological society. A pervasive example of this concern is the Elementary and Secondary Education Act of 1965 and its reauthorization as the No Child Left Behind (NCLB) Act of 2001.

Evaluation of government programs to enhance science education is an ongoing process greatly affected by the political environment as well as the government agency providing the program. Examination of US federal science programs and their evaluation over time highlights the effects of the changing context and its attendant values on science education.

In this chapter, we present the history of federally funded science education programs and their evaluation by examining selected US government agencies involved in science education. We begin with a description of the science-education-oriented federal agencies followed by a definition of multisite science program evaluation. We continue with a history of the multisite science education programs and evaluations in the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), and National Oceanic and Atmospheric Administration (NOAA). We then relate these histories to the changing political contexts and changes in evaluation research and theory.

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US Federal Agencies Providing K—12 Science Education

In 2005, 90% of the $536 billion spent on education came from state and local funding, with only 10% provided by the federal government (U.S. Department of Education [DoEd] 2006). Although the majority of funding for K—12 education comes from state and local sources, the federal government plays an important role in science education in two ways: (1) the federal government passes legislation that affects federal funding, for example, NLCB, and (2) by providing funds for federal agencies to use for education. The role of federal agencies in science education has been reviewed by two federal cross-agency panels since 1993: the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) (Federal Coordinating Council for Science, Engineering and Technology 1993) and the Academic Competitiveness Count (ACC) (DoEd 2007). Both found that federal agencies have an important role in K—12 science education and stressed the need for collaboration and coordination. In testimony of the widespread importance of science education to the federal government, the Academic Competitiveness Council Report (DoEd 2007) discloses that there are currently 12 federal agencies that provide funding for STEM education. Eight of these agencies provide funds specifically for K—12 STEM programs. The report goes on to say that in 2006 federal agencies spent $3.1 billion on STEM education, $574 million (18%) of which supported K—12 science education programs.

Agencies and departments such as NASA, Department of Energy, and NOAA, are designed to provide science services to the nation through such things as the space program, the national energy laboratories, weather mapping, etc. These mission agencies have direct access to scientists and cutting-edge science, but not necessarily educational expertise. They are usually interested in science education in an effort to keep students in the STEM pipeline to provide a strong workforce and support general scientific literacy. They engage in substantial outreach activities, mostly in the form of science education programs (e.g., NOAA's B-WET program). Other mission agencies provide mostly direct services and may have some outreach activities related to science education (e.g., the National Park Service's visitor centers and programs).

The two most important agencies in science education, providing about 85% of the federal funds in 2006, are the (DoEd) and NSF. DoEd's K—12 STEM-specific education budget represents less than 1% of its total 2006 investment (National Research Council of the National Academies [NRC] 2008). Most of the funding presently goes to the Mathematics and Science Partnership (MSP) program, a formula grant program whose mission is to develop rigorous STEM curricula in K—12, distance learning programs, and incentives to entice STEM majors into the teaching profession. MSP-type programs were formerly funded at a higher level under the older Eisenhower program. DoEd supports research through the Institute of Education Sciences (IES) that was established in 2002.

The Education and Human Resources Directorate (EHR) at NSF provides funding for science education through its limited-term grants for educational research, innovative curriculum development and pedagogy, teacher professional development, education programs and activities, and other education initiatives. EHR's budget was about $797 million in 2006, of which around $22 million (30%) supported K—12 science education. Most recently, EHR has increased attention to research on learning and teaching, and has reorganized its research grant programs related to teaching and learning into a single division. Other directorates at NSF also support education initiatives, such as the Directorate for Engineering.

Evaluation of Programs

The Joint Committee on Standards for Educational Evaluation (1994) has defined evaluation as the systematic investigation of the worth or merit of an object. Scriven (1991) suggests that evaluation also includes the identification of relevant standards of worth. These terms (merit, worth, standards) highlight the intimate connection of evaluation with the value systems of the people commissioning, conducting, participating in, and receiving the evaluation. Because it differs in intent, evaluation can be considered distinct from research (Weiss 1988).

All federal agencies are subject to evaluation by the Office of Management and Budget (OMB). The reporting to OMB has taken a variety of forms over the years, most recently as the Government Performance and Results Act of 1993 (GPRA) and the Performance Assessment Rating Tool (PART, available at http://www.whitehouse.gov/omb/part/fy2007/2007_guidance_final.pdf). This tool requires each agency to demonstrate how performance of their programs will be measured. Performance measures can be both long term and annual, and must reflect program goals and include verifiable data collected through reliable research methods. Coupled with PART is the work of the ACC which examined the overlap among federal groups working on science education. As a result, ACC recommended types of designs to use in conducting evaluations of or research about science education programs (DoEd 2007). The granting agencies use a Committee of Visitors process where a team of field-based experts comes into the agency, reviews the quality of the funded proposals, and produces a report. Many reviews have been conducted by the National Academies which was given the authority to advise the USA on scientific and technical matters in 1863. The National Research Council (NRC) was organized by the National Academies in 1916 to associate the broad community of science and technology with the Academy's purposes and has become the principal operating agency. A final method of evaluation is for the agency to contract with an external evaluator to assess a particular program. See, for example, the externally contracted final evaluation report of the Local Systemic Initiative by Banilower et al. (2006).

The history of federally funded science programs and evaluations is one of differing but repeated emphases. These emphases mirror societies' expectations of science programs in terms of curriculum, teacher professional development, student assessment, perceived locus of change, and national leadership and requirements.

Perhaps one of the first implementations of evaluation in the USA was Joseph Rice's comparative study of spelling performance (1898). The next landmark was the Eight Year Study by Tyler and Smith (1942). A 1994 review of science education assessment (Doran et al. 1994) revealed that the 1960s laid the groundwork for present-day science education program evaluation. US federal program evaluation became widespread with the development of the National Assessment of Educational Progress (NAEP), the proliferation of Great Society social programs in the mid-1960s, and the passing of the Elementary and Secondary Education Act of 1965 that mandated evaluations of Title I and Title III education programs (Fitzpatrick et al. 2003).

Questioning the non-utilization and underutilization of evaluations began during the 1970s as evaluators became increasingly concerned about the utility of their evaluations. Such concerns arose in light of economic uncertainty due to recessions and inflation, perceived failures of many Great Society programs in conquering societal ills, and the Watergate scandal that led to great mistrust of the federal government. As quoted by then chairman of the Committee on Labor and Human Resources in the foreword to a volume entitled *Evaluation in Legislation*, "politics has gone from the age of 'Camelot' when all things were possible to the age of 'Watergate' where all things are suspect" (Williams 1979, p. 8).

During the 1980s, maximizing the impact of evaluation became increasingly important. Arguably, three factors contributed to this new emphasis. First, the 1980 election of Ronald Reagan, bringing a fiscally conservative political stance, presented both challenges and opportunities for evaluators. Second was the movement toward professionalization of the field of evaluation. Early steps of this movement included the appointment by a dozen leading educational organizations of a committee of educational evaluators and researchers in 1975 and the subsequent publication of the Joint Committee's *Standards for Evaluations of Educational Programs, Projects, and Materials* in 1981. Third was the advancement of social science methodology. Social science researchers began to value integrative reviews and meta-analyses as forms of research that were complementary and not just secondary to individual research studies. Over time, collaborative and participatory evaluation models began to arise. These models involved planning for use early in an evaluation and involving intended users in the process to increase the effectiveness and tangibility of the process and its findings.

Recently, there have been several trends in evaluation. One is the revision of the Program Evaluation Standards (Joint Committee WMU) and the development of the Guiding Principles for Evaluation (AEA web site), making them more compatible with changing evaluation needs. Another is the emphasis on including diverse perspectives in evaluation planning (Greene et al. 2006) or the culturally responsive approach championed by Mertens (2005). Additionally, as mentioned above, the US ACC (DoEd 2007) advocates a heavily quantitative approach. Lastly, a strong emphasis has been placed on evaluation capacity building and participant involvement in the evaluation process, especially as it relates to increasing evaluation use and influence.

History of NSF K—12 Science Education Programs and Evaluations

As the main federal science education program funder, NSF is a primary example of the effect of history on science programs and their evaluation. NSF's approach to science education programs has been somewhat cyclical. After Sputnik, NSF focused on improving science education through teacher professional development and the construction of new curricula to help win the "race for space." Additionally, the National Defense Student Loan was created to help encourage people to become science teachers by forgiving a portion of the loan for each year spent as a teacher in the program. Evaluation concentrated on the scientific accuracy and effectiveness of these curricula and the newly prepared teachers in helping students learn science.

During the Vietnam era, significant distrust of the government caused NSF programming to switch from large-scale to local programs. These programs were often summer institutes, designed to enhance teacher understanding of science and mathematics and teacher pedagogical skills. Evaluations focused on perceived quality and were individualized to the needs of the programs and their stakeholders (Lawrenz 2007). After continuing for some time, the late 1980s saw an increase in large-scale programs with the Systemic Initiatives. The Systemics included statewide, urban, rural, and local school district programs. Evaluation was much more complex and assessed how to change cultures as well as interactions and the results those changes might produce. This produced the beginnings of national databases to track status information and centralized or pooled approaches to conducting evaluations. In addition, it led to the realization that this sort of evaluation takes a good deal of time and money. Large-scale programs showed up again in the late 1990s with MSP and the Centers for Learning and Teaching. Evaluation was complex with a heavy emphasis on accountability and direct ties to state-based testing systems (Lawrenz 2007). Measures of organizational change and promotion of interaction were developed. Furthermore, several research, evaluation, and technical assistance projects were funded to assist the partnerships with their evaluations (Lawrenz 2007).

Most recently, NSF is emphasizing the research aspects of its programming and is interested in funding transformative ideas. In-service teacher master degree programs have returned as the teacher institute component of the MSP program. The preservice teacher scholarship program idea has resurfaced in the form of the Noyce program. Science program evaluation has moved toward more randomized designs and sophisticated regression-based modeling. Often, yearly achievement data required by the NCLB initiative, national study data such as Trends in International Mathematics, and Science Study (TIMSS) or national longitudinal studies are used.

History of NASA K—12 Science Education Programs and Evaluations

NASA has been in operation since 1958, directly after the launch of Sputnik in October, 1957. NASA's role in K—12 science education is closely linked to and guided by its core scientific, engineering, and exploration missions. NASA provides about 4% of the federally sponsored K—12 education.

NASA has been involved in education since its early years with the Aerospace Education Services Project (AESP) established in 1962. The bulk of the K—12 science education activities are in the Office of Education and the Science Mission Directorate (SMD). Each accounts for about 50% of the agency's total K—12 funding. The SMD devotes a percentage of funds, connected with each major science mission to education activities. The amount of funding for education has been decreasing; for example, the budget for the Office of Education decreased from $230 million in 2003 to $153 million in 2007.

The mechanisms by which these two entities functioned have changed over the years. Prior to 1992, programming was quite independent and K—12 education projects tended to evolve as a diverse portfolio of often disconnected activities. In 1992, however, NASA established its first agency-wide education strategy. The objective for K—12 then, which remains much the same today, was to use NASA's mission to enhance the content, knowledge, skill, and experience of teachers; to capture the interest of students; and to channel that interest into related career paths through the demonstration of the application of science, mathematics, technology, and related subject matter. In 1996, the implementation plan emphasized scientists working in high-leverage partnerships with educators. Most of the education projects in the science and technology enterprises were located in the Office of Space Science (OSS) and the Office of Earth Science (OES). OSS programs generally involved grants for scientists working with educators to provide educational experiences. The OES projects were more traditional in terms of providing curriculum and professional development. The NASA centers played a central role through their education coordinators and the development of center-specific projects. Education coordinators promoted extensive outreach and engagement with local schools and informal science education services.

Recently, NASA programming has been experiencing administrative change due to political pressure. For example, since 2000, NASA educational programs have been organized to align to three different agency-wide strategic plans. In 2003, there was an internal review of the 48 K—12 programs and only those perceived as effective were continued. The OSS and OES were merged into a new directorate that includes the majority of the mission-oriented educational programs. Most recently, all K—12 projects are to focus primarily on attracting and retaining students in science disciplines through engagement and educational opportunities. K—12 projects are divided into four major categories, educator professional development of less than 2 days, educator professional development of more than 2 days, curricular support resources, and student involvement. Coordination and management of the various programs has been distributed to the various centers.

Only a limited number of evaluations have been conducted on these programs. Only three of the programs, the NASA Explorer School, the Aerospace Education Services Project, and the Science Engineering Mathematics and Aerospace Academy, have been substantially evaluated. As part of the NRC (2008) report, a detailed critique of the available evaluations of the NASA programs was also prepared. The critique provided information about the methods and the results of NASA evaluations.

All evaluations reported on how the program was operating and how that operation fit within NASA goals. All provided recommendations as to how the program might be improved or changed. Most provided a good deal of information about how the participants in the program felt about the program. Overall, they provided very interesting descriptive information about the programs from the perspectives of those involved. However, the samples used to gather evaluation information were often convenience samples; meaning the people used were those from whom data were easy to obtain. Results yielded perceptions that were overwhelmingly positive. There were only a very few small attempts at comparative studies and these were flawed by selection bias; one group was likely to have been different from the other at the start.

History of NOAA Science Program Evaluations

Although NOAA was first formed in 1970, the agencies that came together at that time are among the oldest in the federal government. The agencies included the US Coast and Geodetic Survey formed in 1807, the Weather Bureau formed in 1870, and the Bureau of Commercial Fisheries formed in 1871. As the USA's leading oceanic and atmospheric science and service agency, NOAA has the responsibility to increase its coordination and collaboration within the ocean, coastal, Great Lakes, weather, climate science, and education communities. The administration has had a federally mandated educational mission since at least 1966 with the passing of the National Sea Grant College and Program Act. Most recently in 2007, NOAA's role in earth system science education was solidified by the America Competes Act. This legislation provided NOAA a mandate to advance its educational efforts, and engage a broader community of partners in creating an environmentally literate society as well as a viable workforce of scientists, managers, and administrators in support of a sustainable future (National Oceanic and Atmospheric Administration [NOAA] 2008b). The high interest at NOAA for evaluation is exemplified by the first outcome listed on its Education Strategic Plan ("evaluation and research for effective programs" (NOAA 2008b).

NOAA's organizational chart shows its Office of Education as reporting separately from the six operating branches. Both the operating branches and the Office of Education provide science education programs. The Office of Education and the agency-wide Education Council were formed in 2003 as part of the agency's commitment to environmental literacy as a cross-cutting priority. Programs are provided in both formal (K—12 schools, colleges, etc.) and informal settings (after school programs, museums, etc.) for teachers, students, and the general public of all ages. NOAA partners with other agencies and professional groups to help develop its educational programs. For example, the Essential Principles of Ocean Literacy (National Geographic Society 2006) and Essential Principles of Climate Literacy (NOAA 2008a) were developed to help guide educational efforts. The Office of Education operates an Environmental Literacy grants program which began in 2005. As of 2007, this program provided $1.6 million for Science on a Sphere projects in science museums and centers as well as $6.8 million to 15 free choice and K—12 formal education programs. The 2006 budget showed the following breakdown of education and outreach areas: Climate (2%); Weather and Water (2%); Ecosystems (43%); Commerce and Transportation (5%); and Mission Support (48%).

NOAA has a broad array of science education programs and these programs have been affected by the political environment. NOAA has responded to the differing national science education agendas by providing ocean education, environmental education, and most recently, climate change education. Much work has been done to counteract the perceived lack of emphasis on earth sciences in the National Science Education Standards. Some programs directly focused on K—12 science education are Sea Grant, Ocean Exploration, Teacher at Sea, Storm Ready/Tsunami Ready, Bay Watershed Education and Training Programs, and Jason.

As one of NOAA's longest funded educationally related programs, the Sea Grant program has been the most evaluated. In fact, in addition to a comprehensive regular evaluation procedure involving external review and rankings, the program was twice evaluated by the National Academies. The first report in 1994, A Review of the NOAA National Sea Grant College Program, suggested changes to the comprehensive regular evaluation review procedures (NOAA 1994). In 2006, a second evaluation (NOAA 2006) examined the effects of the 1994 report in Evaluation of the Sea Grant Program Review Process. Almost all of the NOAA educational programs are evaluated in some way. Overall the evaluations are much like those described for NASA, although the NOAA evaluations tend to be more quantitatively oriented.

In 2007, the National Academies were requested by the NOAA Office of Education to review the NOAA education programs. This 3-year review will result in a comprehensive report addressing the role of NOAA, the appropriateness of its goals and objectives, the effectiveness of the educational programs, the composition of its education portfolio, and the quality of the evaluations of its programs. Including evaluation as one of the major questions for the review highlights the importance of evaluation and accountability within the agency.

Implications

The US federal government plays an important role in science education, even though its total contribution to the K—12 education budget is relatively small. The agencies, especially NSF, are viewed as providing a leadership role in what is important for science education. Mission agencies such as NASA and NOAA also play an important role in promoting their specific areas of science education. All agencies provide their programs as incentives for schools to participate; however, schools are not required to participate. Even federally mandated programs such as NCLB are voluntary with the withdrawal of federal support used as an impetus to participate.

Other governments around the world have similarities and differences in terms of the way they participate with K—12 level science education. For example, in Singapore, science education in the grades corresponding to the US K—12 system is nationally supported through the Ministry of Education. The Ministry also supports the National Institute of Education as its research arm, much like the US Institute for Educational Sciences. Although Singapore's government does support science research agencies like the USA's National Institutes of Health (NIH), those agencies are not engaged in K—12 science education. Singapore has a national curriculum, one part of which is science.

As another example, in Australia a national curriculum is just being developed (beginning in 2009) whereas in the past each of the states had developed its own curriculum, much like in the USA. Until very recently, most of the funding for the equivalent to K—12 education flowed through the Australian federal government into the states. The states functioned mostly independently, although the federal government made suggestions as to how the money should be used. This is also similar to the US DoEd's flow through block grants to the states, although the withholding of federal money is enough of a stick that most states in the US conform to federal recommendations.

This review has documented the types of science programming and concomitantly, program evaluation experienced in three federal agencies. These show that federally sponsored science programs and their evaluations are closely tied to political agendas and contexts. NSF science education programming emphases have been somewhat cyclical, oscillating from large to local programs and from implementation to research as public opinion of the government and government priorities have changed. NASA science education programming emphases have been responsive to public opinion about space programs and science and engineering as appropriate career paths. NOAA science education programming has reflected the public interest in the environment, especially oceans and weather. As the emphases in science education programs differ, the evaluations differ in terms of what they value and how they measure valued outcomes. In recent years, there has been more emphasis on gathering summative data for accountability and consequently there has been much less emphasis on formative evaluations across all federal agencies. Despite recent calls for more comparative studies to assess accountability, programs or even projects within agencies are seldom compared, much less programs compared across agencies. Despite this proclivity, there have been attempts to look across agencies (e.g., ACC and FCCSET). The US government agencies tend to pass along their own requirements for evaluation (e.g., GPRA and PART) to the programs with which they work. National interest in the goals of the agencies appears to govern the type of programming more than the results of evaluations. For example, climate change is an important recent topic and programs on climate change will be supported, regardless of evaluation data.

A consistent and increasingly more salient goal across the agencies has been expanding the diversity of people engaged in science and science education. For example, many directorates at NSF fund programs to attract underrepresented groups, and NOAA has a diversity council to address these issues. Similarly, NASA has several related programs including the Introduce a Girl to Engineering Day. Not only are science programs provided to explicitly address issues of underrepresentation, but also to attend to cultural responsiveness (e.g., Mertens and Hopson 2006). The recent revision of the NSF's *User-Friendly Handbook for Project Evaluation* includes a chapter on culturally responsive evaluation (Frechtling 2002).

It is clear through the many reports, acts, and laws surrounding science education that the US federal government is very interested in science education. Its rationale for that importance changes from strategic military needs, to prestige, to economic advantage. However, the call for improvement is consistent. The involvement of the different agencies makes the response somewhat ad hoc, but concurrently responsive to individual needs and interests. It is unlikely that most K—12 science educators are aware of the plethora of science education experiences that are available. Much of the programming is accessible in limited geographical areas or to select people through word of mouth. This is truly unfortunate. Science educators should call for more coordination of the federal programming and more efficient information dissemination techniques. A coordinated program with each agency contributing what it does best would likely be more efficient than the existing independent programming.

If a federally coordinated program existed for science education, evaluation could be conducted on a larger scale and produce more generalizable results. In turn, this would help to increase the effectiveness of the programming. If such evaluations were possible, science educators should advocate for diversity of perspectives and methods, as well as high quality and rigor. Critical and interpretive methods (e.g., Coghlan et al. 2003) should be balanced with more positivistic approaches (DoEd 2007). It would also be important to evaluate the effectiveness of the different evaluation methods being used to examine science education. As a result, the methods themselves could be improved (Burkhardt and Schoenfeld 2003). Finally, although there has been work identifying the essential competencies required of an evaluator, there is no clear indication of what skills might be explicitly needed for science program evaluation (Stevahn et al. 2005).

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Part VI
Curriculum and Reform

Chapter 49
Curriculum Integration: Challenging the Assumption of School Science as Powerful Knowledge

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Curriculum Integration Defies Definition

To define curriculum integration, we first must consider curriculum. David Scott (2008) said that curriculum can refer to a system at a number of levels including national, institution or school and that it has four dimensions, including aims or objectives, content or subject matter, methods or procedures, and evaluation or assessment. To create a definition or description, it is probably most helpful to consider curriculum integration in relation to the second of these dimensions, that is, the content or subject matter of a curriculum. This dimension is related to questions about what knowledge should be included and what items excluded in a curriculum and how these items of knowledge should be arranged (Scott 2008). Dominant modes of curriculum in the twenty-first century are focused on established, canonical knowledge located within disciplines such as physics, mathematics, history and literature. The disciplines themselves almost always provide the structure of the curriculum (Scott 2008). This is widely referred to as a disciplinary, or traditional, approach to curriculum.

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In our own work we found that curricula that are referred to as 'integrated' can take on a number of forms that can only be described as 'different' from the traditional approach to curriculum. In a previous review, we came to the conclusion that curriculum 'integration is a particular ideological stance which is at odds with the hegemonic disciplinary structure of schooling' (Venville et al. 2002, p. 51). All curricula with which we are familiar include some form of disciplinary knowledge. It is the structure of the curriculum that determines whether it can be considered disciplinary or integrated. For example, Charles Anderson and colleagues (2008) describe learning progressions through upper elementary and high school that focus on preparing students for environmentally responsible citizenship. One of the learning progressions is 'Water' and includes the role of water and substances carried by water in earth, living and engineered systems (including the atmosphere, surface water and ice), groundwater, human water systems, and water in living systems. Anderson et al.'s learning progression can be considered integrated. While it contains disciplinary-based concepts, it is not structured around the traditional disciplines of science such as biology or chemistry, or other non-science disciplines such as geography.

Marlene Hurley (2001) found the existence of multiple forms of integration throughout the twentieth century and suggested that there seems to be a paradox between the demand for a general definition of integration and research that illustrates a need for multiple definitions. The demand for a definition is ongoing – see Charlene Czerniak's (2007) overview, for example. During the 1990s, some researchers described curriculum integration along a continuum (e.g. Drake 1998) but others (e.g. Panaritis 1995) criticised this approach because of the implication that movement along a continuum is progress towards a better state. In our own research, we used a definition of curriculum integration that is inclusive of the broad spectrum of implemented curricula that we have observed:

> An integrated curriculum enables students to look toward multiple dimensions that reflect the realities of their experiences outside and inside school. (Venville et al. 2008b, p. 860)

With such a broad definition, a number of progressive programmes reported in the literature could be considered integrated. For example, contextualised instruction (e.g. Rivet and Krajcik 2008), authentic tasks (e.g. Lee and Songer 2003), community connections (e.g. Bouillion and Gomez 2001), science technology and society (e.g. Pedretti 2005), place-based education (e.g. Guenewald and Smith 2008), democratic schools (e.g. Apple and Beane 1999), futures studies (e.g. Lloyd and Wallace 2004) and youth-centred perspectives (e.g. Buxton 2006), all include approaches to education that involve students looking towards multiple dimensions that reflect the real.

Curriculum Integration as a Contentious Issue

Integrated approaches to curriculum remain a contentious issue, with ardent commentators presenting a number of arguments either supporting or opposing its implementation in schools (Hatch 1998). These arguments have tended to be either epistemological (focused on the structure and utility of knowledge) or affective (focused on students' attitudes and engagement with science). On the epistemological front, disciplines create a sense of order about the complex world and provide students with the specialised knowledge that they need to solve complicated, discipline-based problems or to create rigorous explanations of focused aspects of the world. For example, Howard Gardner (2004) argued:

> The disciplines are important human achievements. They are the best answers that human beings have been able to give to fundamental questions about who we are, physically, biologically, and socially. (p. 233)

Alan Schoenfeld (2004) pointed to research that shows that 'disciplines matter in teaching and learning to teach' (p. 237) and that '[c]lassroom activities must foster active engagement with the content and processes of the discipline, with students developing and testing ideas in ways consistent with the paradigms of the disciplines they study' (p. 238). Michael Young (2008) claimed that 'knowledge that takes people beyond their experience has historically been expressed largely in disciplinary or subject forms' (p. 10) and suggested that the disciplines are the epistemological price that we pay for a better understanding of the world.

Supporters of curriculum integration argue that knowledge in the real world is holistic and the division of knowledge into subjects for teaching and learning in schools is a historical artefact and simply a pragmatic method of curriculum delivery (Hatch 1998). Dan Young and Nathalie Gehrke (1993) point out the paradox of the phrase 'curriculum integration', which is supposed to reflect the notion of wholeness and coherence, the totality and unity of existence. The paradox comes from the suggested need, particularly in school systems, to patch together the disciplines to create a whole. 'We do not need to create the whole: the whole already exists' (Young and Gehrke 1993, p. 447). Others argue that learning for adolescents is about life experiences in familiar contexts and relationships and interactions that they have with trusted people and that compartmentalized, disciplinary knowledge and narrow reasoning processes are not consistent with this way of understanding knowledge (O'Loughlin 1994).

On the affective front of the debate, supporters refer to the statistics showing adolescent disengagement with traditional approaches to schooling and suggest that integrated approaches to curriculum motivate and interest students in ways that disciplinary content, delivered in traditional pedagogical ways, fails to do. Science teacher, Elaine Senechal (2008), for example, claimed that a multi-disciplinary project in which she was involved, about air quality in the surrounding school environment, was 'a powerful tool for engagement and motivation' (p. 105). Other commentators go further and suggest that the reason why an integrated approach to teaching and learning tends to be more engaging for young people is that it better reflects the realities of students' experiences outside school; 'it makes learning more applied, more critical, more inventive, and more meaningful for students' (Hargreaves et al. 2001, p. 112). Michael Apple and James Beane (1999) explain that integration:

> …involves putting knowledge to use in relation to real life problems and issues… Rather than being lists of concepts, facts and skills that students master for standardized achievement tests (and then go on to forget, by and large), knowledge is that which is intimately connected to the communities and biographies of real people. Students learn that knowledge makes a difference in people's lives, including their own. (p. 119)

Apple and Beane's comments, made in 1999, reflect another powerful argument that is currently impacting the perceived role of science within the curriculum, namely, connection to 'real problems', 'real lives' and the 'real world'. Edgar Jenkins (2007) argued that students need better, more realistic ideas about the multiple realities of what constitutes science in the real world and wonders 'whether a subject-based curriculum can provide students with the inter- and cross-disciplinary perspectives required to respond to challenges of this [global] kind' (p. 278). The 'real world' argument can be considered to be both epistemological and affective, because it responds to issues related to knowledge and emotion, and perhaps reflects both these arguments in unison.

'Scientific Perplexities' of the Real World

The problem with most real-world issues in which adolescents of today are likely to be interested is that they are part of science, where Jerome Ravetz (2005) explained, facts are uncertain, values are in dispute, stakes are high, and decisions are urgent; these factors make these topics difficult to define and difficult to assess. Ravetz (2005, p. 11) bids '[f]arewell to the old classifications, such as physics, chemistry, biology' and welcomes 'new ones, like GRAIN – short for genomics, robotics, artificial intelligence and nanotechnology'. Ravetz claimed that these new sciences involve a complex of issues and that, whatever the solutions, they will neither be determined by science alone, nor will they be simple or easy. He refers to them as 'scientific perplexities' (p. 33) that are beyond what Thomas Kuhn referred to as 'normal' science.

One example of a contemporary scientific perplexity is the notion of environmental sustainability. Ravetz (2005) claimed that the growing realisation, since the 1960s, that our industrial civilization is unsustainable and that we are polluting ourselves and exhausting key resources, has changed our perception of reality. This change, according to Ravetz, is a revolution in thinking, somewhat akin to the Copernican revolution or the revolution of Charles Darwin's Theory of Evolution by Natural Selection. This notion of a 'paradigm shift' is also reflected in the writings of Fritjof Capra (e.g. 1982) who claimed that 'we live today in a globally interconnected world, in which biological, psychological, social, and environmental phenomena are all interdependent' and that 'the holistic conception of reality, [is] likely to dominate the present decade' (Capra 1996, p. xviii).

We have noted previously that a common thread in many integrated programmes in schools is that they have connections with the environment in some way (Wallace et al. 2007). A quick glance at recent National Association for Research in Science Teaching annual international conference programmes reveals terms such as global climate change, sustainable development, global atmospheric circulation, environmental action projects, climate, energy use and air quality, environmental knowledge and attitudes, ecological literacy, ecosystems understanding, and ecomorphism. For example, Nir Orion and Carmit Cohen (2008) discuss a new module, 'Oceans and the earth systems', that has been developed as part of an environmental-based interdisciplinary component of the Israeli high school earth sciences program. Real-world scientific perplexities, including the issues of environmental sustainability, are clearly becoming part of the real world of science education.

Discordant Metaphors of Science as Both a 'Holistic' and 'Fragmented' Discipline

We note a dissonance in the metaphors in the literature about science in our modern, global society of the twenty-first century. On the one hand, metaphors reflect 'holistic', global science; on the other hand, the metaphors reflect the 'fragmented' nature of science as a discipline. For example, Capra's (1996) thesis is that earlier schools of science based on mechanistic, easily quantifiable models are in opposition to the holistic awareness of today's scientific phenomenon. In biology, Capra suggested abandoning the concept of the cell as a fundamental building block of life, and suggested the cell be thought of in symbiotic partnership with organelles and other cells. Chaos theory, as described by John Briggs and David Peat (1999), encourages scientists to go beyond their mathematical and scientific origins and embrace myth, mysticism, poetry, literature, art, religion and philosophy to create an interconnected view of the universe, our world, our society and ourselves. A more classroom-based example of the holistic metaphor is presented by Michelle Lunn and Anne Noble (2008). By establishing clear links between art and aesthetics and science as a creative process, these researchers demonstrated that science is holistic and can encompass emotions that traditionally have been considered unscientific (such as wonder, love and passion) and that formed natural connections with art, music, dance, meditation, yoga and processes of imagination.

In stark contrast with the holistic views of science discussed above, others point to the fragmentation of 'science' into a chaotic array of sub-disciplines or specialties. Lyn Carter (2008) explored the implications of globalisation for science education and noted the 'increase in the sheer size and scope of contemporary science research in increasingly fragmented subdisciplines' (p. 625). Moreover, Jenkins (2007) argued that science in schools is promoted as a 'coherent curriculum component' but further argued that, in reality, it 'fosters an untenable but enduring notion of a unifying scientific method that ignores important philosophical, conceptual, and methodological differences between the basic scientific disciplines' (p. 265).

A Variety of Factors Impact on the Implementation of Integrated Science Curricula

Jeong Suk Pang and Ron Good (2000) commented that many variables can significantly affect the success or failure of integrated programmes. These include teachers' variables, such as subject matter knowledge, pedagogical content knowledge and beliefs, as well as their instructional practices. Other factors might be contextual, such as administrative policies, curriculum and testing constraints, and school traditions. Our own research (Venville et al. 2008b) showed a strong relationship between educational context and the way in which an integrated, community-based project about the environment was implemented. Within the context of a traditional high school, we found that the form of curriculum integration implemented was quite different from that implemented in a purpose-built middle school with a similar demographic. The contextual factors included such things as school organisation, classroom structure, timetable, teacher qualifications, collaborative planning time and approach to assessment.

Factors inhibiting curriculum integration in many ways match, but also oppose, the enabling conditions. Factors working against curriculum integration include community wariness that integrated teaching approaches might be 'watering down' the curriculum (Wallace et al. 2007). Ellen Brantlinger and Massoumeh Majd-Jabbari (1998) found that, while college-educated, middle-class parents espoused support for open, integrated, multicultural, student-centred education, their narratives actually revealed a preference for conservative practice. They preferred factual, tightly sequenced, subject-area-bound and Western-oriented curricula because, the authors suggest, generations of their class have had relatively uncontested success within this traditional approach to curriculum. An integrated curriculum is not consistent with the expectation in many places that the school curriculum should be academically oriented, emphasising written work and individual study and focused on examinable concepts and ideas (Kaplan 1997).

Teachers with different disciplinary backgrounds and the high turnover of staff in some schools also provide barriers to ongoing curriculum integration. For teachers, teaching out-of-discipline, content knowledge was found to impact on both their confidence and ability to teach science in a reform-based manner (Kruse and Roehrig 2005). This is often compounded with beginning teachers who have limited pedagogical knowledge and experience in managing classroom activities. Lee Shulman and Miriam Sherin (2004) argued that 'one of the most significant factors influencing the effectiveness of teaching … is the teachers' own subject matter knowledge and pedagogical content knowledge' (p. 136). Ralph Levinson (2001) found that it is challenging, even for science teachers, to address the ethics and controversies of contemporary science issues. He concluded that few teachers, whatever their speciality, can handle these areas with much confidence or expertise, but he noted that this is not due to any inadequacy on their part, but to the complexity of the issues. Collaboration between teachers with different disciplinary expertise is certainly possible, as we have seen in our own research between mathematics, science and design and technology teachers (Venville et al. 2000), but it is not easy. Jeff Marshall et al. (2007) encouraged interdisciplinary cooperation as a minimum for integrating physics and mathematics in order to increase meaning and relevance for high school students.

The Nature of Science Learning from Integrated Curricula

Evaluations of science learning that result from integrated programmes of work in schools have produced notoriously ambivalent conclusions. In a review of the literature from the 1940s to the early 1990s, Gordon Vars (1991) found more than 80 normative or comparative studies reporting that, on standardised achievement tests, students in various forms of integrated programmes performed better than, or at least as well as, students enrolled in separate subjects. Colin Marsh (1993) tracked some of the major research on integration from the USA, UK and Asia over the previous 50 years and found that there was limited evidence of either a positive or a negative effect. David Perkins and Rebecca Simmons (1988) noted that assessment of learning in integrated settings tends to focus on the disciplinary content and neglect other factors that could be more consistent with an integrated approach to teaching and learning. Hurley (2001), for example, limited her meta-analysis to quasi-experimental research that measured achievement in the science and/or mathematics disciplines. The results from 31 studies showed that, overall, student achievement effects for science were slightly larger than for mathematics (effect size of $d = 0.37$ compared with $d = 0.27$ standard deviations), suggesting that curriculum integration is better for science than it is for mathematics achievement. She identified multiple forms of curriculum integration and found that, when examined with achievement effects, these forms had different outcomes. Science achievement was greatest when mathematics was used in total integration with science or to enhance science. In contrast, both these forms had small effects for mathematics achievement. Student achievement effects were greatest for mathematics when it was taught in sequence with science, that is, when the subjects were planned together conceptually, but taught separately.

Some studies have attempted to incorporate broader and more holistic perspectives into their evaluation of student learning, focusing on outcomes such as student motivation, attitude, cooperation and capacity to transfer and apply knowledge. In the 31 studies included in her meta-analysis, for example, Hurley (2001) noted anecdotal evidence that curriculum integration has a positive impact on attendance, student discipline, knowledge of academic resources, study habits, student enthusiasm and student engagement. Specific examples of recent research into student learning with broader perspectives might include work conducted by Stephen Ritchie et al. (2008) who investigated, through an interpretive methodology, what happened when a class of fourth-grade children co-created, with their teacher, a publishable eco-mystery that integrated both fiction and non-fiction. They found that the activity maintained the students' interest and motivation and enabled them to demonstrate fluency with, and understanding of, scientific phenomena as well as develop their literacy skills using both narrative and factual genres. Moreover, Anne Rivet and Joseph Krajcik (2008) found a correlation between science achievement and the frequency with which students verbalised links between science ideas and a project that they were examining that involved the context of a bicycle helmet and safety.

In our own research, we found that, when data were viewed from a science discipline-based perspective, the learning of science concepts in integrated classroom contexts might not be as robust as might be expected if the teacher had focused on a conceptual change approach (Venville et al. 2003). If the same data were scrutinised from an integrated perspective, however, then learning outcomes such as students' ability to transfer ideas from one context to another, the application of science understandings to practical contexts, and students' general motivation and perception of the relevance of their school work were recognised and valued (Venville et al. 2000). Further still, we found that other forms of learning, such as the students' use of sources of knowledge to make key decisions about integrated projects, could be another way of defining the success of an integrated project (Venville et al. 2004). We have previously suggested that evidence about the impact of integrated programmes on student learning has not been easily identified, or might be understated because of the difficulty that researchers have in finding a way of viewing 'learning' that is consistent with the holistic view of knowledge underpinning integrated curricula (Venville et al. 2008b). The kind of learning documented can be different depending on the theoretical and/or methodological framework which the researchers adopt.

What Is Powerful Knowledge in Science?

Gregory Kelly et al. (2008) argued that, in many current, education-based debates, questions about knowledge have the underlying assumption that there is a corpus of canonical, disciplinary or received wisdom that is beyond criticism. They further assert that these assumptions are translated in curriculum documents into key criteria, standards or educational outcomes that are narrowly focused on what is readily measurable or amenable to standardised achievement testing. Julie Bianchini and Gregory Kelly (2003) concur and describe the Californian science curricula standards as a long list of scientific facts that students are expected to master and suggest that they have a regressive flavour of received wisdom. 'As more and more attention in the schools turns to the issue of preparing students for high-stakes tests, there is a real risk of reducing the opportunities for students to engage in contextually authentic science… [The] consequences are particularly salient to urban children of poverty who are often most at risk of failing to meet these external mandates' (Buxton 2006, p. 719).

Evidence to support Buxton's (2006) assertion is provided by Wayne Au (2007), who showed that the primary effect of high-stakes testing is that curricular content is narrowed to those subjects included in the tests, subject-area knowledge is fragmented into test-related pieces, and teachers increase the use of teacher-centred pedagogies. Kelly et al. (2008) claim, however, that there is a new generation of international scholars who question the nature of academic disciplines and that a new way of viewing knowledge is emerging. An example of this new way of viewing knowledge is provided by Richard Duschl (2008) who argued that science classrooms should be conceptualised as ‘epistemic communities’ (p. 277). According to Duschl, science learning and assessment should focus on three integrated domains: conceptual structures and cognitive processes; epistemic frameworks used when developing and evaluating scientific knowledge; and social processes and contexts that shape how knowledge is communicated, argued and debated.

In contrast, Michael Young (2008) expressed concern that recent trends to reduce subject-specific content and include broader perspectives, such as those suggested by Duschl (2008), while perhaps more engaging and relevant to students, inevitably disadvantages some children, particularly those from poor families with low levels of social capital. He argued that disciplinary knowledge is ‘powerful knowledge’ (p. 14) because of the intellectual power that it gives to those who have access to it. In a similar vein, Na’ilah Suad Nasir et al. (2008) argued that denying students the opportunity to acquire powerful knowledge (in this case, mathematics) is a disservice, particularly to students from disadvantaged social circumstances. They asserted that mathematics knowledge acquired in everyday contexts should only be used as leverage to support, and not to limit, students’ deeper engagement in more abstract mathematics that will give them access to higher education and more choices in potential occupations.

Young (2008) claimed that Basil Bernstein’s concept of knowledge structures is one way of exploring the possible implications of different forms of curricular organisation. Bernstein (e.g., 2000) used the concepts of ‘classification’ and ‘frame’ to describe the underlying structure of curriculum. Classification refers to the degree to which the content in a subject differs from other subjects. Framing refers to the amount of control that the teacher and students have over the selection, organisation and pacing of the content in a subject. Lesley Parker (1994) found that the more strongly classified and framed a subject is, the higher is its status. Subjects such as physics and history, being strongly classified and framed, have high status, whereas subjects such as environmental science have weaker classification and framing and thus lower status. Cornelis de Brabander (2000) found that teachers considered subjects with everyday knowledge to be ‘soft’ (i.e. not easily tested), subjective and open to debate. Subjects containing ‘hard’ academic knowledge were testable, objective and well established. All these systems of examining the status of knowledge indicate that the more discipline-based a subject is, the higher its status, and the more integrated it is, the lower its status.

Our own recent research (e.g. Venville et al. 2008a), however, illuminated a case study of integrated classroom teaching and learning that opposed this view that highly framed and highly classified disciplinary knowledge can be considered powerful knowledge. We observed students learning about the health of a nearby lake. The implemented curriculum was weakly framed because the boundary between what was taught and learned and what was not taught and learned was not clearly defined. The content varied and was determined by the interests of the individual students and the teacher. The topic also was weakly classified because the content of science was not well insulated from the content from other school subjects including society and environment, english, mathematics, art and technology and enterprise. The kind of learning observed in this case study could also be considered to be ‘soft’ (i.e. difficult to test in an objective way), subjective and relatively open to debate. In this case study, the absence of high-stakes testing enabled a broad spectrum of content to be considered at inconsistent depths by different students and a broad spectrum of innovative teaching strategies. The teachers justified these approaches by claiming that the students ‘need stimulation’ and that the approaches helped students to ‘respond’, gave them ‘ownership’, made them ‘empowered’ and ‘connected to their own world’, ‘changed their attitudes’ and, finally, resulted in them ‘actively making decisions and changing their world’.

We contended that the very factors that were considered to render the topic as weakly classified and weakly framed through schema such as Bernstein’s were the very factors that also indicated the power for students of this approach to learning. The power of the knowledge taught and learned during the case study was that it was integrated and provided the students not only with powerful scientific knowledge, but also with powerful values in social and civic responsibility, power to think in ways that are appropriate to the problems and issues that face the community in which they live, power to communicate and debate these issues, and power to think about ways in which these problems and issues can be addressed.

Conclusion

In this chapter, we have described seven points of tension around which the issues of curriculum integration circulate. The first point of tension is that there are multiple forms of curriculum integration described in the literature and this multiplicity defies a focused definition. Second, curriculum integration is a contentious issue with commentators presenting convincing arguments for and against its implementation in schools, based on both epistemological and affective perspectives. Third, contemporary and real-world science includes a number of complex ‘scientific perplexities’ (including environmental sustainability) that are difficult to consider from within a single discipline and, at the same time, require a depth of knowledge from a number of disciplines to understand. Fourth, the discipline of science itself reflects opposing metaphors that suggest it is becoming a more holistic, interconnected discipline and simultaneously a more fragmented and disparate discipline. Fifth, there are a number of factors that impact on the implementation of an integrated curriculum with the status quo seeming to be a disciplinary approach. Sixth, science learning outcomes that have been measured from integrated approaches to curriculum are neither excellent nor poor. Measuring learning outcomes other than content knowledge that can be more relevant to an integrated curriculum is difficult and often ignored by both teachers and researchers. Finally, powerful knowledge has traditionally been knowledge from within the highly defined and highly insulated school disciplines. While this continues to be the case in most school contexts, there is mounting evidence that integrated teaching and learning can leverage a different kind of power for students.

All of the factors discussed in this chapter are adding to the complexity of what should be included in the science curriculum and to the contentiousness of how science should be taught in schools. The important question is about the degree to which we can abandon science as a coherent, well-insulated and established discipline that offers students a profound framework of knowledge and processes on which to base their learning. As we asked in a previous review (Venville et al. 2002), is it necessary for the high ground of science as a school subject to be eroded away entirely for curriculum integration to take place? Is school science under threat from curriculum integration and new, holistic world views? How can science as a school subject coexist with more holistic approaches to teaching and learning? These questions are worthy of our serious attention.

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Chapter 50
Risk, Uncertainty and Complexity in Science Education

Clare Christensen and Peter J. Fensham

Social issues involving science and technology are increasingly attracting public attention. Their importance is underpinned by the urgency they are accorded by the scientific communities, and the priority given to them in the mass media. Governments now include specific ministers for Energy, and Water, as well as the longer recognised Environment. The importance of these issues is now so evident in many countries that schooling that ignores them can be accused of selling short its current students as future citizens.

The American Association for the Advancement of Science, in the 125th Anniversary issue of *Science*, identified a number of Grand Challenges and Great Opportunities. In 2000, the National Research Council (NRC 2000) identified grand challenges in environmental science and the Gates Foundation then specified 14 grand challenges for global health. In 2008, economical solar energy, access to clean water, a secure cyberspace, preventing nuclear terror, and enhanced virtual reality were listed as grand scientific challenges by the National Academy of Engineering.

Douglas Roberts (2007) directed the attention of science educators to two different visions for developing the teaching and learning criteria for scientific literacy (SL). Vision I gives meaning to scientific literacy by looking inward at the canon of natural science. Vision II derives its meaning from the character of situations with a scientific component that students are likely to encounter in their lives. The grand challenges involve the situations referred to in Vision II.

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Table 50.1 Comparison of the features of the science of priority issues with traditional school science

Science of priority issues	Traditional school science
Interdisciplinary	Discrete disciplinary strands
Multi-disciplinary, including non-science aspects	Non-science aspects used only for motivational purposes
Knowledge is uncertain	Knowledge is firmly established
Scientific perspectives alone can distort the reality of the issues	Science knowledge alone needed for idealised or contrived situations
Possibilities and probabilities are solution goals, not a single, correct solution	Learning involves reproduction of static knowledge and established principles that lead to one single correct answer to problems
Uncertainty introduces the idea of risk as a feature of solutions	Scientific reasoning does not include risk and probability

The 2007 World Conference on Science and Technology Education in Perth, Western Australia brought some of these issues to the science education community. Lord Robert Winston (biomedical issues), Graham Pearman (global warming issues), Howard Gardner (issues involving multiple intelligences) and Ian Lowe, (energy and other conservation issues), each described a set of issues of great significance. Such issues that are multifaceted in nature, involving several scientific disciplines, and aspects of economics, social philosophy and ethics are commonly referred to as socio-scientific issues (SSI).

The science of these socio-scientific issues contrasts quite starkly with traditional school science, as illustrated in Table 50.1.

The differences in these features in Table 50.1 are so great that science teachers face a new paradigm for science when considering teaching these important issues in school classrooms. The great majority of science teachers will not have been educated about such a paradigm for science, but rather in one that reflects the canonical science they have hitherto been teaching.

Before discussing how science education has responded to, and needs to adapt in the new paradigm, some of its key ideas – *risk*, *uncertainty*, *complexity*, *probability*, *the precautionary principle* and *decision making* need further elaboration.

Risk and Science

In school, and in society more generally, science has been presented as a highly reliable (if not ‘certain’) body of knowledge with the capacity to provide explanations for phenomena and solve practical problems. In so many areas its application has demonstrated this reliability. Nevertheless, the social theorists Ulrich Beck and Anthony Giddens have argued that, alongside this record of success, science and its associated products and technologies increasingly challenge people with new uncertainties and risks.

Risk, they claimed, is the dominant cultural theme of the late twentieth and early twenty-first centuries. In *Risk Society: Towards a new modernity*, Beck (1992) argued that risks are continually increasing and are not equitably distributed within and across societies. Alongside the problem of sharing wealth across communities and nations, there is now the global challenge of the distribution of risk, for which the world community is not well equipped. The failure of international attempts to eradicate poverty and disease, to find alternative solutions to warfare and immense destruction, and now to meet the challenge of global warming are all familiar examples of Beck's claims. He acknowledges that risks have always been present in human society, but that their nature is changing, with many more of them now being due to the human interventions that accompany technologies and products, often based on new scientific knowledge. This link with scientific knowledge makes Beck's thesis very pertinent to science educators.

Beck could have been described as alarmist in 1992 since he refers to 'irreversible harm' (p. 23) and 'apocalyptic catastrophe' (p. 60). However, since then the same phrases have been increasingly used by expert scientists, making the general public rightly concerned about proliferating man-made risks that may be associated with new medications, genetically modified foods, global warming, using mobile phones, and technologies with nano-sized particles. There are more long-standing concerns about the risks of nuclear power, and of living near high-voltage power lines, telecommunication towers, and toxic waste dumps, all related to 'scientific progress'. The adult community struggles with these new uncertainties, especially if personal decisions are involved.

Giddens (1990) saw successful existence in modern society depending simultaneously on trust in proliferating expert systems on the one hand and, on the other, a deepening reflexivity that demands justification and accountability from them. Citizens, individually and institutionally, want to monitor and ask questions as they try to cope with a world of increasing uncertainty and risk. Beck (1992) agrees that citizens constitute an 'alert and critical public' (p. 19), and sees this as evidence for his claim of a developing reflexivity in late modernity. The development and employment of technologies (in the environmental, social and personal realms) are increasingly raising questions about the political and economic management of their risks. His definition of risk as 'a systematic way of dealing with hazards and insecurities induced and introduced by modernisation' (p. 21) includes public responsiveness. Alison Shaw (2002) provided a case of public engagement in her exploration of lay understandings of genetically modified food. She described how scientific arguments about risk have now entered everyday discourses about food, and how food debates are commonly framed as risk issues. UK and European governments have responded to these concerns with new regulatory bodies to protect health and restore confidence in food. The challenges of assessing, managing, and communicating risk in the face of scientific uncertainty are central to the work of these bodies.

Beck argued that scientific knowledge has, and has been given, special significance in relation to assessments of risk. Environmental issues are framed in terms of the science involved, at the expense of their social, cultural and political meanings. The risks are thus considered only in terms of the scientific (or anti-scientific) knowledge about them. Furthermore, since the risks are imperceptible in most cases, they require the 'sensory organs' of science – theories, experiments, measuring instruments – in order to become visible as hazards.

Ortwin Renn (1992) also noted the prioritising of the scientific among seven conceptions of risk derived from different academic disciplines. Three of these he categorised as technical conceptions in which risk is seen as an objective property of an event or an activity, measured as the probability and magnitude of possible harm, a more static view than Beck's more dynamic one above. Economic, psychological, social and cultural conceptions of risk see it as culturally or socially constructed. The anthropologist Mary Douglas criticised the technical conception of risk for 'its abstractness, its power of condensation, its scientificity, and its connection with objective analysis' (Douglas, 1992, p. 5). She proposed that cultural influences play a major role in how people focus on particular dangers in their lives, judging risks according to their knowledge/information, the kind of people they are, and the influence of their cultural beliefs. This socio-cultural perspective influenced Deborah Lupton and John Tulloch's (2002) study of public perceptions of genetically modified foods. They examined 'the narratives, epistemologies, discourses, rhetorical moves, choices of "rational arguments" and courses of action which people use to organize "risk" as a cultural concept' (p. 320).

Brian Wynne (2001) challenged the dichotomous way the issue about genetically modified crops and food was being promoted as the binary of risk versus ethical concerns –objective versus subjective. This patronises the public through the portrayal of their risk concerns as solely about ethics and intellectually vacuous. Wynne argued that what is missing from so-called objective assessments of risk are the unknown uncertainties. Scientists and their institutions, he noted, have been unwilling to acknowledge the limits and contingencies of the knowledge they advance.

Complexity and Science

The grand challenges facing the scientific communities are described as *complex* because they involve uncertainty and multi-disciplinarity. Complex issues involve uncertainty because they share two features that are different from even the very complicated problems that science has been so successful in solving. The first uncertainty arises from the science itself, either because of the intractable nature of the phenomena involved, or because uncertainties have been incompletely resolved before decisions about them must be made. The second uncertainty arises from the multi-variate nature of the issues, which means that two properly conducted investigations can produce findings that are conflicting because different variables were chosen for study. Finally, the multi-disciplinary nature of the issues means the expertise from a number of scientific and non-scientific disciplines has to be involved, making judgements about decisions subject to incommensurable information. Complexity Theory provides a tool (see later) that is useful in differentiating the degree of complexity in science-based issues.

Uncertainty, the Precautionary Principle and Science

Brian Wynne (1993) listed some uncertain features of the science in socio-scientific issues that are contrary to the certainty that pervades most school science. These are:

- Risk: system behaviour is known and outcomes can be assigned probabilities
- Uncertainty: important system parameters are known, but not the probabilities
- Ignorance: not knowing that other factors may be important
- Indeterminacy: causal chains, networks or processes are open and thus defy prediction.

The issues in the grand challenges have heightened the need to recognise these uncertainties and apply precaution in making decisions about them. The idea of precaution in interpreting scientific data and evidence has a long history (Harramoës et al. 2002). The Precautionary Principle marks a shift from post-damage control to a pre-damage control of risks. It was given high status and urgency by the World Conference on Science in 1999, and the World Commission on the Ethics of Scientific Knowledge and Technology was charged with developing a working definition for it:

> When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm.
>
> 'Morally unacceptable' refers to harm to humans or the environment that is
> - Threatening to human life or health, or
> - Serious and effectively irreversible, or
> - Inequitable to present and future generations, or
> - Imposed without adequate consideration of the human rights of those affected (UNESCO 2005, p. 14)

A number of currently publicised socio-scientific issues are readily associated with each of these grounds for moral unacceptability.

The judging of one scientific hypothesis as plausible, and another as not, is not because its probability is greater. Rather, it is because the plausible hypothesis has more serious possibilities for harm than the other. Until there is more evidence to indicate a clear difference in the probabilities of the two hypotheses, we should suspend our scientific judgement about which is true. But we should not suspend our practical judgement. The Precautionary Principle suggests we should be wary of deciding for the hypothesis of greater harm.

Drawing attention to the uncertainties in the consequences of rising earth temperature is a classic example of the main scientific bodies invoking the Precautionary Principle in the months preceding the Inter-governmental Copenhagen Conference on Climate Change in 2009. In summary, the Precautionary Principle applies in cases where there are scientific uncertainties and there are models of possible harm that are scientifically plausible. In these cases uncertainties cannot be reduced without increasing ignorance of other factors; morally unacceptable conditions apply and there is a need to act now because later action will be more difficult or more costly.

Decision Making and Science

Although decision making involving scientific knowledge has become a regularly stated aim of school science education little guidance has been provided for teaching these personal and social processes. It seems to be assumed that acquiring definitive science knowledge is all that is needed. Decision making by human beings is, however, rather more complex than this, even when the science aspects are free of uncertainty.

Amos Tversky and Daniel Kahneman (1974) analysed human decision making and found that, far from applying normative utility theory, people commonly apply heuristics and biases, both individually and socio-culturally derived. These biases are not necessarily irrational or detrimental, as people making decisions pursue a variety of objectives, framing a problem in different ways. Most approaches to remove bias involve consideration of alternative perspectives that can minimise the initial framing effects.

Engaging with socio-scientific issues effectively in science classrooms will require science teachers to encourage students to express and examine different views of a problem and to place scientific knowledge in its broader multi-disciplinary context.

Public Understanding of Socio-Scientific Issues

The studies by David Layton et al. (1993) of citizens in a range of situations involving science heralded a new frontier for science education researchers. The situations included parents of Down's syndrome children, elderly persons and domestic heating, and residents living near nuclear processing plants. The findings highlighted the 'fragility of much of the available science and its inability to provide unambiguous answers to questions asked' (p. 118). The title of their report, *Inarticulate Science*, points directly to a feature of science that, hitherto, science educators would have directed to their respondents, rather than to science itself. These studies also raised issues about the trustworthiness and reliability of the sources of scientific information in decision making.

Alan Irwin and Brian Wynne (1996) echoed these findings in nine other cases of public involvement with science-related issues. Scientific arguments, presented as value-free, played an important role in the framing of the discussion of these issues.

This was problematic because this scientific framework was not value-free, being determined by social as well as technical factors. Many members of the public do not share the assumption of the superiority of scientific knowledge at the expense of social knowledge with which they are more familiar. Jenkins (2000) concluded from these studies that the 'world proves to be much more complicated, uncertain and risky than school science encourages students to believe' (p. 211), foreshadowing the paradigm shift for school science education that this chapter is outlining.

Risk in Public Understanding of Science Studies

Subjective framings of risk become evident when socio-scientific issues are debated, and these are often at odds with expert scientific thinking. In community responses to science, risk and trust are intertwined as they often are in situations of uncertainty.

The *Programme on Understanding Risk* (2001–2005) in the UK was set up to develop theoretical understanding of public framings and attitudes towards science and risk issues. Wouter Poortinga and Nick Pidgeon (2003) asked a large sample of adults to share their perceptions of five contemporary issues that raise public policy questions – climate change, mobile phone radiation, radioactive waste, genetically modified foods and genetic testing. A majority of participants indicated interest in all five issues, but needed more information about the risks.

The links between science, risk and trust are also demonstrated in a New Zealand study by Rosemary Hipkins et al. (2002); they investigated how the thoughts, feelings and attitudes of adults contribute to their views of science across a range of public health issues. Most participants recognised the importance of developments in science and technology for the economy and for advancing of knowledge. Many, however, had a high level of concern about the consequences of developments and expressed attitudes to science that related to their feelings of trust towards scientists, attitudes also found by Clare Christensen (2007) among Australian young people considering the health risks of mobile phones.

Judith Petts et al. (2003) conducted a similar study of adults in the UK, meeting in a focus group to discuss the vaccine for measles/mumps/rubella, air pollution and mobile phones. These researchers introduced the idea of 'risk literacy', and argued that its development must begin in school science.

Studies of public concern about global warming (Bulkeley 1997) and genetically modified foods (e.g. Shaw 2002) found that risk and trust inevitably arose in the discussions of 'expert' scientific knowledge, which participants perceived to be complex and uncertain, even for scientists.

Strong evidence for the usefulness of risk understanding was provided by Sandra Duggan and Richard Gott (2002) in a study which investigated the kinds of scientific knowledge lay adults needed for making personal decisions on three local issues: the emission effects of burning recycled liquid fuel in a local cement kiln, the siting of a mobile phone base station near a primary school and the choice of immunising young children. Understanding of the concept of balancing risk, the associated probabilities, and the precautionary principle was ‘crucial’ for personal decision making on each issue.

Jim Ryder has analysed 31 public understanding of science studies (some with well-established and some contested science), in order to develop a framework for ‘functional scientific literacy’ in school science education concerned with citizenship. He found that content knowledge was important in some issues, but in general was not as central to decision making as knowledge about science. Six categories of knowledge, he argued, are necessary for effective lay interactions with scientific issues: subject matter knowledge, collecting and evaluating data, interpreting data, modelling in science, uncertainty in science and science communication in the public domain. He concluded that where there is uncertainty risk understanding is fundamental – knowing that decisions may need to be made of the basis of risk estimates and recognising that risk estimates may not be available.

In the wider community scientific knowledge is frequently associated with judgements of risk and trust. It follows that these dimensions of risk and trust should be included in school science if it is to prepare students to deal with contemporary socio-scientific issues.

Risk in School Studies

In an early study, Harrie Eijkelhof (1986) evaluated senior secondary students’ participation in *Ionising Radiation*, a trial module in the PLON project for innovative physics education in the Netherlands. He found that these students did have the capacity to make risk judgements that matched actual risk statistics.

Whilst classroom studies of discussions of socio-scientific issues now constitute a growing domain of research (Sadler 2004), the role of risk understanding and risk judgement has rarely been addressed. A notable exception is a study by Stein Kolstø (2006) in which students’ discussions of the safety of high-voltage power lines in their community were examined. Scientific risk estimates were provided, along with economic, geographic, psychological and political information. All students used the risk information and it proved to be central in their decision making. Kolstø concluded that science education has an important role to play in developing students’ understandings of the concepts of risk and uncertainty.

Complexity Theory – Simple, Complicated and Complex Contexts for Science Education

The simplicity of the contrived contexts presented in school science contrasts so considerably with the complexity of the science to be taught in relation to the grand socio-scientific issues that it is useful to tease out some of these differences.

Established Laws Hold	Uncertainty Holds
simple cases ***risk*** ***zero or very low***	*complex cases* ***risk*** ***high to very high***
complicated cases ***risk*** ***low to medium***	***CHAOS*** ***risk*** ***out of control***

Fig. 50.1 A basic form of the Cynefin Framework

Cynthia Kurtz and David Snowden (2003) invented the *Cynefin Framework*[1] to help people to make sense of complicated and complex situations. It takes the form of a 2 by 2 matrix as shown in Fig. 50.1. The left-column sectors are for cases and phenomena for which well-established laws hold, together with assumptions about order, rational choice and singular intent. The right-column sectors are for cases and phenomena in which a degree of uncertainty holds, along with assumptions like incomplete order, choice not merely rational and lack of agreed intent.

In the column under **Established Laws Hold**, the two sectors of the matrix allow for a differentiation between simple cases involving one science principle or perhaps a short sequence of principles, and complicated cases where a mix of different principles is involved and where sequencing may have options. In the column under **Uncertainty Holds**, the cases in the top sector are designated as complex because of their uncertain or not completely understood character. This uncertain character leaves open extreme possibilities that then fall into the lower-right CHAOS sector.

The introduction of the distinctions of simple, complicated and complex as a characteristic of a phenomenon introduces risk of varying degrees of significance as an important feature to be considered.

Examples from Medical Science

Some familiar medical phenomena illustrate the use of the Cynefin Framework and its terminology for differentiating phenomena and situations. A *broken arm* is a simple case. It is fully understood why bones break and how to set them so that they will restore themselves.

[1]Cynefin' is a Welsh word meaning the place of our multiple affiliations.

A heart by-pass operation is a complicated case. Medical science fully understands how to detect the condition of blocked arteries, and how to remedy it with by-pass arteries, justifying an expensive, extended open-heart operation that was impossible 50 years ago. The multi-staged procedure is long and involves the combined efforts of differently skilled medical personnel. However, for these professionals, the operation is now quite routine and the risk associated is low.

AIDS is a complex case, still not understood or curable after more than 20 years of intensive study. Some progress has been made in controlling its rate of onset and its progression, but these involved big changes in social behaviour along with the regular application of costly drug regimes. In some countries these controls have been established too late, or are not possible, and the illness has become a pandemic and locates in the CHAOS quadrant.

Context in Traditional School Science and in the Grand Challenges

School science has traditionally drawn heavily on contexts that are ideal or contrived. The ideal contexts, like frictionless surfaces, ideal gases, solutions without activity, and very simple Mendelian genetics, provide *simple cases* that locate in the top-left sector of the Cynefin Framework. Thought experiments involving such ideality have been important in the derivation of scientific principles, and for these ideal cases the established laws hold precisely. Contrived contexts are ones that give an appearance of reality but, in fact, are reduced so that the established laws still hold and can be directly used to solve problems that are posed within them. They also locate in the top-left sector. Teachers often use contrived contexts to try to engage their students.

The lower-left sector locates actual situations where friction exists, where forces exist between gas molecules, where there are interactions between solute particles and with the solvent, and where inheritance is controlled by multiple genes on more than one chromosome. In these cases established principles still hold, but their formulation and application are more complicated. Internal and external interactions need to be heeded, and additional principles included that were ignored in the simple cases. Putting a person on the moon and breeding new strains of wheat are examples of very complicated cases involving numerous physical and biological interactions, but they are fully understood and we all know some of the incredible outcomes that have followed from their careful application.

Most of the Grand Challenges are contexts of sufficient complexity and uncertain science that they locate as complex cases in the top-right sector of the Framework.[2] An example close to us as Australian authors is forest fires. These present complex, multi-variate socio-scientific situations about which the science is not fully understood. They pose high risk to human life, but the knowledge about them is usually enough

[2]Jerome Ravetz (2006) used the term ‘perplexity’ for these contexts.

Natural Laws of Science Hold	Uncertainty Holds
simple cases **90% of School Science (idealised or contrived contexts)** **answers:** *only one correct (knowledge from established science)*	*complex cases* **"possible School Science" ("open S&T projects, SSI")** **answers:** *possibilities & probabilities (recognising balance and uncertainty in knowledge and its interactions)*
complicated cases **10% of School Science (context-based contexts, open-ended laboratory exercises)** **answers:** *one or more correct (knowledge from several sciences)*	***CHAOS*** **answers:** *search for difficult reversals to stability*

Fig. 50.2 Locating school science and science education for socio-scientific issues in the Cynefin Framework

to provide some control. The combination of conditions on February 7, 2009 in Victoria tipped the fires that day over to CHAOS. Thousands of properties, 200 human lives and many more livestock and native fauna were lost.

A complex context now generally familiar to all is global warming. The uncertainty of scientific knowledge about its phenomena locates it in the top-right sector. Some scientists, however, believe that the warming is advancing so rapidly that 'tipping points' like affecting the Gulf Stream cannot now be avoided. If they are right, the global warming would move to the CHAOS sector. The people of some Pacific nations like Tuvalu and Kiribati are already teetering on this intersection to CHAOS.

Applying the Cynefin Framework to the contexts of traditional school science and to those that now need to be included in the curriculum for the years of primary and secondary schooling leads to Fig. 50.2.

In Fig. 50.2, the risk feature in the Cynefin Framework has been replaced with its inverse, the certainty implied for the intended answers to the questions that are usually posed in school science assessment. Probable and alternative answers need to be added to the traditional single correct answer.

The disciplinary character of traditional school science and of the socio-scientific education associated with the Grand Challenges is well differentiated in Fig. 50.3.

School science is located in the upper left-hand sector of Fig. 50.3 since it almost entirely based on single scientific disciplines, being applied to ideal or contrived contexts. The Science Technology Science (STS) movement among science educators in the later 1980s provided strong arguments for, and interesting topics involving technology that needed a more interdisciplinary science approach in school science

Natural Laws of Science Hold	Uncertainty Holds
Simple cases **Single science disciplinary topics**	*Complex cases* **Multi-disciplinary SSIs (Grand Challenges)**
Complicated cases **Interdisciplinary science (STS as technological applications of science)**	***CHAOS***

Fig. 50.3 The disciplinary nature of the science in the traditional science curriculum and in the socio-scientific issues education of the Grand Challenges

(Solomon and Aikenhead 1995). It recognised the importance of topics that had real-world meaning for students and such meaning is rarely mono-disciplined. The real-world examples in these STS trial curricula locate as complicated cases in the lower-left sector of the Framework.

The new curricula for school science in the 1990s did not follow the STS direction, and retained, across the years of schooling, mono-disciplinary science strands, even in countries that had had for many years a single subject called Science below the senior levels. Little, if any, attention was given to the many Science and Technology phenomena and situations that involve more than one science discipline and the interdisciplinary scientific concepts that are needed for understanding and measurement. The science in these 1990s curricula remained located in the upper-left sector. By their disciplinary definition of subject content and assessment practices, these curricula avoid the possibility of being relevant to the lives of most students. Their focus is firmly on Douglas Roberts' (2007) Vision I of scientific literacy, and their intentional direction is not concerned with preparing students for today's grand challenges. In the light of the urgency of the socio-scientific issues that began this chapter, and the revisionary character of so many current science curricula, Glen Aikenhead (2006) reformulated the hopes and directions of STS education in terms of a plea for a more humanistic science education. The contrast between the characteristics of humanistic science education and traditional science education are listed in Table 50.2, and are closely related to the contrast between traditional school science and the science in the Grand Challenges and the SSI education that began this chapter.

The interdisciplinarity of the science involved in the socio-scientific issues of the Grand Challenges is compounded by essential features that involve non-science disciplines. In this sense they are 'multi-disciplinary'. The uncertainty of how all these different disciplinary elements interact, adds to the uncertainties in the science, and further contributes to their location in the upper-right sector in Fig. 50.3.

Table 50.2 Characteristics of humanistic and traditional science education

Humanistic science education	Traditional science education
Citizen preparation for the everyday world	Pre-professional training for the scientific world
Attention to several sciences (established science, frontier science, citizen science)	Emphasis on established science only
Moral reasoning integrated with values	Solely scientific reasoning using scientific habits of mind
Knowledge about science and scientists	Knowledge of canonical science

Teaching Complex Socio-Scientific Issues – The Grand Challenge for Science Education

As a first new skill for teaching socio-scientific issues, science teachers will need to learn to differentiate between the variety of contexts they may wish, or be required to include in their teaching. The Cynefin Framework with its way of locating the uncertainty associated with simple, complicated and complex cases is useful here.

For issues in the complicated cases sector, a science teacher can use established knowledge from the several sciences involved, together with the appropriate interdisciplinary concepts, to lay out the optional solutions.

For socio-scientific issues that locate in the complex cases sector science teachers should be wary of embarking alone on the task of teaching them. This may come as a relief to many science teachers who have been reluctant to extend their teaching beyond the simplicity of disciplinary ideality. Few science teachers are equipped to do justice to the multi-disciplinary aspects of these issues. To attempt do so is likely to lead the students to see the issue as essentially technical, for which the solution is in the hands of scientists.

The urgency of including the socio-scientific issues of the Grand Challenges in school science is such that they cannot be avoided on these grounds. Rather, new ways of teaching them must be developed. Science teachers must begin by acknowledging the importance of the socio-scientific issues' other dimensions – ethical, social, economic, etc., while indicating their primary role is to provide deep understanding of the scientific dimensions. Troy Sadler and Dana Zeidler (2008) have developed a framework for addressing socio-scientific issues in terms of the psychological, social and emotive growth of the child, ensuring that these multiple dimensions are considered.

Several alternative ways of including the non-science dimensions have been suggested. One way is for teachers from relevant disciplinary areas agreeing to take up the same issue contemporaneously for a number of lessons. This approach was adopted in a middle school curricular innovation in Queensland called *Rich Tasks* (Education Queensland 2004). In a Year 9 rich task, *Science and ethics confer*, students identified, explored and made judgements on a biotechnological process that had ethical dimensions.

A second approach is to plan an 'educational event' over one or several days. This requires more organisational adjustment for a school, but provides a rich learning opportunity. Teachers plan together how to introduce their differing disciplinary perspectives on the chosen issue. Students in small groups then engage in extended activities that develop these perspectives in more detail. Finally, the students feed the alternative dimensions into the whole class to see what coherence about the issue can be reached and what possibilities for resolution can be proposed.

Educational events like these have been described by Bev Farmer (1994) and Léonie Rennie (2007) for in-school and out-of school learning, respectively. The careful planning needed is similar to classes going on field trips, visits to galleries, museums, etc. In primary schooling teachers who are accustomed to an integrated approach to teaching find these 'educational events' a relatively simple extension of their practice.

Kolstø (2000) proposed a 'consensus model', based on adult community consensus conferences that have been used in several countries. Students work in groups, each group researching one main aspect of the issue. These 'expert' groups then report to and are questioned in a whole class event by a 'lay' group who listen to the varying perspectives and work towards a consensual opinion on the issue. This teaching approach assumes that decision making should be both values-based and knowledge-based.

Equipped with new awareness of socio-scientific issues and the sense that science has a key role, but not a dominant role, science teachers will then need to develop new pedagogies. These must be consonant with the nature of the uncertain science and the risk and trust that are characteristic of this new paradigm. The old transmissive pedagogy that seemed consonant with the authority of established science knowledge will need to give way to socio-cultural approaches in which ambiguity and uncertainty are encouraged and tolerated. Large-scale evaluation of the UK national curriculum *Core Science* (UYSEG and Nuffield Foundation 2007), which is based on contemporary socio-scientific issues, has confirmed the need to develop new science teaching skills if reforms of science education towards the goal of citizenship are to proceed effectively.

Some practical guidelines were suggested by Mary Ratcliffe (1997) and Vaille Dawson (2001), including classroom formats for debates, forums, hypotheticals, drama, simulation games, seminars, role plays and activities outside of school. They advocated the use of explicit decision-making structures, such as cost–benefit analysis and bio-ethical principles to assist students to deal with the complexity of issues.

Such pedagogies allow students' voices and opinions to be aired, challenged and changed. The absence of opportunities to participate fully in traditional science classrooms, has been identified by students as a major ground for their dislike and disinterest in school science (Lyons 2006).

These pedagogies will be new procedures for many science teachers. Roger Cross and Ronald Price (1996) explored Australian science teachers' initial experiences of dealing with socio-scientific issues. The teachers needed help with clarifying the purposes of such discussions, with their own content knowledge of the issues, and with the management of discussion, particularly the non-science dimensions.

Ralph Levinson and Sheila Turner (2001) and Tom Bryce and Donald Gray (2004) found similar reactions from English and Scottish teachers. In relation to biotechnology issues Bev France (2007) drew attention to the influence that teachers' own conceptions of biotechnology might have on how they engage students with such issues.

Parallel with these more practical studies appropriate pedagogical models are being theorised. Chris Oulton et al. (2004) argued that an important basis for the new pedagogy is the need for the nature of controversial issues to be understood by both students and teachers. They defined controversy by differences in value judgements, seeing bias as an essential part of controversy. The task then becomes developing students' capacity to be critically aware of bias. This suggests the kind of 'critical science literacy' advocated by Jay Lemke (2002). Oulton et al. argued that teachers' fear of being accused of bias is currently one of the barriers to effective teaching of controversial issues.

Ralph Levinson (2006) used the nature of controversies to develop a framework for pedagogy. This consists of three strands – nine categories of reasonable disagreement, nine communicative virtues and both narrative and logico-scientific modes of thought. Categories of disagreement describe different scenarios where the roles of evidence and social dimensions vary in their capacity to resolve the issue. Levinson suggests that articulating these categories of disagreement can show students how disagreements arise from the varying interplay of evidence, values and worldviews. The narrative mode is important as an opportunity for students to convey meaning to the science of the issue and to stimulate further questioning.

Another theoretically based approach to pedagogy has been teaching about argument in science. Rosalind Driver et al. (2000) demonstrated how a contemporary view of the nature of science must give a central place and role to argumentation. Argumentation studies of students engaging with science content and with socio-scientific issues now constitute a growing domain of research in science education (Driver et al. 2000).

Developing argumentation and small group discussion skills are likely to assist students to develop confidence in dealing with issues involving uncertain or controversial science. Ray Brown and Peter Renshaw (2000) introduced a pedagogy called collective argumentation, based on Carl Bereiter's (1994) idea of science as progressive discourse. They sought to create 'more diverse communicative spaces in the classroom, that is, spaces for speaking and engagement that differed from the typical IRE [initiation, reply, evaluation] formats in classrooms where teachers do the majority of talking and thinking' (p. 53). In collective argumentation, students establish and follow rules of discourse for discussing novel and complex problems. In mathematics classrooms, this approach has shown promise for developing in students collaborative discussion skills important for citizenship.

Much more research on professional development is needed to prepare science teachers to engage with socio-scientific issues and dimensions such as risk in classrooms.

Assessment

Two international projects assessing science learning provide a contrast relevant to the issue of placing socio-scientific issues in science education. The IEA's Third International Mathematics and Science Study (TIMSS), in 1994, exemplified the type of science education in the left top sector of Fig. 50.3 (Albert Beaton et al. 1996). The science items, presented as isolated topics, all have just one right answer and they relate to single disciplinary sciences. This project continues as Trends in Mathematics and Science Study and essentially measures students' recall of science content, commonly taught to 8 and 14 year olds across many countries.

In 1998, the OECD launched the Programme of International Students Achievement (PISA) that also set out to measure the science learning of 15 year olds, but with a very different charter. It was to provide countries with information about how well students were prepared for life in the twenty-first century. Accordingly, the PISA project set out to measure how students could apply their knowledge of science from whatever source, to contemporary real-world contexts involving science and technology (OECD 2006). A number of cognitive and affective items reflecting clearly defined scientific competencies were asked about a series of these contexts. The science in these situations is interdisciplinary and items with more than one right answer were common. The PISA assessment test for scientific literacy locates regularly in the lower-left sector of Fig. 50.3, but only rarely, and then more as affective items, in the upper-right sector.

Sadler and Zeidler (2009) complimented the PISA project's vision of scientific literacy for their general consistency with the socio-scientific issues perspective, but are critical that its items do not link sufficiently to the presenting context and fail to pursue its non-science dimensions, particularly the moral dimension. They have recently experimented with new approaches for assessing socio-scientific issues as learning outcomes. These include students' *reflective judgement* – a construct that represents an individual's perspective on knowledge and justification of knowledge. King (2008) has produced a computer-based form for assessing this construct via the Reasoning about Complex Issues (RCI) Test. Sadler and Zeidler suggest that four invariant practices do have general applicability across many socio-scientific issues. These are: (a) appreciating the inherent complexity, (b) analysing issues from multiple perspectives, (c) recognising the need for information about the uncertain nature of the science and (d) employing scepticism in the review of information provided by parties with vested interests. The tasks intimately connect to specific socio-scientific issues, but also have more general application.

Conclusion

Modern societies that are very significantly defined by science and technology are where lives of current and future citizens have to be enacted. Rather than becoming simpler, these societies are increasingly concerned with issues that are 'complex' in the way complexity is defined in this chapter. The science schooling of future citizens cannot responsibly ignore the challenges these science and technology situations pose.

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Chapter 51
An International Perspective on Science Curriculum Development and Implementation

Richard K. Coll and Neil Taylor

Science curriculum development and implementation internationally have been enacted in an enormous variety of educational contexts. According to Richard Coll and Neil Taylor (2008a), curriculum development in so-called developing countries, the principal focus of this chapter, often involves external 'experts' in imposing Western curricula in educational contexts that are very different in economic, political and cultural terms – a sentiment alluded to earlier by Brian Gray (1999). Such curricula are often delivered in English, which is a second or third language for many students and teachers in non-Western settings as reported by Chanyah Dahsah and Richard Coll (2008). Considering what we now know about the importance of context in the learning process as noted by Albert Pilot and Astrid Bulte (2006), and the influence of culture as reported by Lilia Reyes-Herrera (2007) and Ken Tobin and Wolf-Michael Roth (2006), it is perhaps not surprising in retrospect that curriculum development and implementation have been less successful than hoped (Van Eijck and Roth 2007). A number of authors have pointed to the disconnection between cultural, religious and social issues in developing countries as they grapple with the implementation of imported Western science curricula. For example, Olugbemiro Jegede and Peter Okebukola (1991), along with Gerad Thijs and Ed Van Der Berg (1995), point to a mismatch between ideas about knowledge and scientific knowledge (see also Mbajiorgu and Iloputaife 2001). Konai Helu-Thaman (1991), a Pacific Island education scholar, rather depressingly commented that the Pacific is littered

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with the 'wreckage' of aid-funded curricular initiatives of this nature, and argues that it is important to get to grips with the reasons for such failure.

In this chapter, we present an analysis of science curriculum development internationally. We consider the history of curriculum development and implementation in science, seek to ascertain what we can learn from the problems and issues encountered, and make recommendations to inform future curriculum revisions in developing nations.

International Curriculum Development and Implementation

Developing countries have invested heavily in school science education since the 1960s, mostly in order to foster economic development and improve the quality of life. However, by the beginning of the last decade, Keith Lewin (1993) reported concerns about instructional quality and student achievement were becoming acute which, according to Henry Brown-Acquaye (2001), pointed to problems with the appropriateness or implementation of science curricula. A variety of developmental approaches have been tried out, with the outright adoption of curricula from Western countries – typically the colonial power – being the most common approach.

Clive McGee (1997) says curriculum development and implementation in most countries, including developing nations, have involved the centre-periphery model. Typically, this is dominated by central government or officials charged with implementation. In a critique of curriculum development and implementation in 25 developing nations, Richard Coll and Neil Taylor (2008b) identified several key themes: the *pace of curriculum development*; the *political dimension*; the almost universal *adoption of a learner-centred curriculum*; issues to do with *the assessment regime*; and a relative paucity of *contextualised evaluation*. These themes form the framework for the following analysis of curriculum development and approaches to implementation.

The pace of curriculum development and implementation is exemplified by two contrasting examples. In the first, Turkey, Muammer Çalik and Ayas Alipaşa (2008) observe that, over a relatively short period of time, four major revisions and 11 different versions of the science curriculum were promulgated from 1924 to 2005, with six since 1968. Indeed, they note that Turkish teachers have never actually managed to implement a particular curriculum fully before it was replaced with a new version. The sheer pace of educational development in terms of growth in student numbers is exemplified by the case of Bhutan, for which Tom Maxwell (2007) reports that school enrolments rose from virtually zero, to 130,000 in a few decades. It seems likely that this level of growth would cause problems, but Tenzin and Maxwell (2008) rather surprisingly suggest otherwise, saying that the curriculum development was measured, contextualised and well managed.

The political dimension is seen in the value of education, and science education in particular, being linked to the economic and technological modernisation of developing nations (Koh et al. 2008). This notion was particularly prevalent in the

1980s and 1990s says Aaron Benavot (1992), and such thinking continues to this day (World Bank 2008). At the societal level, Keith Lewin (1993) feels that education, especially basic or elementary science education, has the potential to improve living conditions through addressing basic local issues such as the provision of clean water, sound nutrition and personal health. It was such considerations as these, associated with basic human needs, which prompted the Science for All paradigm arising from the UNESCO Minedap V conference (UNESCO 1986, p. 137). It seems that the principal driving force behind science curriculum development and reforms is the so-called *economic imperative*, with many developing nations seeking to improve standards of living by enhancing economic development.

Many developing nations had very traditional science curricula up until about the 1980s. But the 1980s and 1990s witnessed 'explosive' curriculum reforms worldwide, including in developing countries, and arguably the single most commonly shared attribute of these curricula was their constructivist origins described by Beverley Bell et al. (1995). Learner-centred education, with its origins in constructivism (and variants of constructivism) and focus on outcomes (Rogan and Grayson 2003), became something of a mantra according to Joan Solomon (1987). Richard Coll and Neil Taylor (2008a) believe that this was largely driven by a perception that, because developed or Western nations had developed constructivist-based curricula, developing nations feared being left further behind economically and strove to adopt a learner-centred curriculum as rapidly as possible in order to overcome reliance on subsistence agriculture or production of primary produce – something claimed to be the prime source of tenacious poverty in many developing nations (World Bank 2008). According to Martha Montero-Sieburth (1992), even if not directly based on constructivism, other curriculum development efforts also were learner-centred in nature.

Graham Vulliamy (1988) comments that, before the educational reforms of the 1980s and 1990s, assessment in developing countries was dominated by a series of high-stakes, external, summative examinations (see also Postlethwaite 1991). Furthermore, these examinations largely focused on lower-level cognitive skills such as recall. Whilst developing nations have since attempted to develop and implement learner-centred curricula as noted by Hsin-Kai Wu and Ya-Ling Huang (2007), Richard Coll and Neil Taylor (2008b) argue that they seldom have made commensurate adjustments to their assessment regimes. Consequently, examinations still dominate the education system in developing nations. Plainly such examinations are inconsistent with learner-centred education, because the examinations consist of tests of memory recall, which encourage rote memorisation of scientific 'facts'. This is by no means unique to developing countries. Anne Hume and Richard Coll (2007), commenting in the context of New Zealand, reported that the development of a matched assessment regime trailed curriculum reforms by nearly 10 years. But, the situation in many developing countries is often much more severe and is compounded by limited secondary school places and highly competitive examination systems such as in India as observed by Mridula Ranade (2008). However, there are signs of hope, with Neil Taylor et al. (2003) reporting that Fiji, once dominated by a series of five gate-keeping external summative examinations, is now embarking on a rather radical shift towards competency-based assessment. This change will be part of a major reform of education, beginning with primary science, involving the development of a new student-centred curriculum and accompanying resources. The crucial difference from previous curriculum development projects is that the assessment system will also be reformed with a move away from external summative examinations and the introduction of elements of continuous assessment as described by Neil Taylor et al. (2008). Without this move away from external summative examinations, there would be little prospect of a change in pedagogy, as teachers would continue to employ the transmissive teaching strategies that have always proved successful under the examination regime.

The best educational reforms and the most sophisticated curricula – even if well matched to an assessment regime – are likely to prove fruitless unless reforms and implementation of new curricula are accompanied by adequate teacher professional development. Teacher professional development, according to Shirley Grundy (1995), has typically been of the 'pit stop' or 'one shot' variety that consists of a series of one-off teacher professional development workshops run by ministry officials soon after the official launch of new curricula. Josef De Beer (2008) comments that, even nowadays, the normal response to such an approach is 'business as usual'. In other words, teachers look to see how they can continue with existing teaching practices in the 'new' curriculum, albeit with a little tinkering so that it appears that things have changed in the way intended. Chanyah Dahsah notes this is exactly what happened in Thailand. A learner-centred curriculum was developed in the 1990s and duly 'implemented' (Dahsah and Coll 2008). But her research suggests that many Thai teachers had little appreciation of what learner-centred education actually means (despite being readily able to recite definitions) in terms of teaching practice. The development of learner-centred curricula has been accompanied by recent local research into how actually to deliver such curricula, mostly with a focus on constructivist-based pedagogies such as the use of analogies reported by Muammer Çalik et al. (2007, 2009). However, despite the introduction of a new learner-centred curriculum, teaching remains didactic in nature in most Thai schools.

It seems that, despite enormous amounts of money being spent on curriculum development and reform (some local monies, much foreign aid from international organisations or NGOs), relatively little evaluation research has been conducted. Certainly a number of developing nations have participated in international monitoring projects such as TIMSS reported by Heiner Rindermann (2007) and PISA reported by Vassilia Hatzinikita et al. (2008), but contextualised, local evaluation or research efforts, with a few exceptions, remain modest. Chao-Ti Hsiung (2007) reports that Taiwan has embarked on substantive efforts to conduct local research, and much of this is evaluative in nature. In Thailand, the situation is similar, and this is driven by a research institution charged with improving science education by means of research – the Institution for Promoting Science and Technology (IPST) his institution which funds a substantial PhD program in science education, with many Thais being sent overseas for doctoral studies and then encouraged to continue in research when subsequently appointed to teacher training institutions upon their return, as described by Chockchai Yuenyong et al. (2008). However, Muammer Çalik and Ayas Alipaşa (2008) caution that often even high-quality local research might not make much difference in the classroom, partly because it is not seen as relevant to or accessible by teachers. Difficulties identified are the habitual ones associated with many constructivist-based teaching strategies, such as those noted by Ken Tobin and Debora Tippins (1993) – taking more time to cover the curriculum, something highly unpopular when teachers are faced with a crowded curriculum as reported for the Solomon Islands by David Sade and Richard Coll (2003), or a lack of resources for delivering practical work as noted by Michael Kahn (1990). The other main cause is that alluded to above, namely, inconsistencies between the assessment regime and a learner-centred approach to teaching. Teachers are evaluated in terms of performance based on pass rates in summative examinations. Indeed, in many countries, school examination pass rates are published in local newspapers and league tables. It would be a brave teacher indeed who engaged in learner-centred education, if she or he feased it adversely affected school pass rates.

Lessons Learned and Recommendations for Curriculum Development and Implementation in Developing Nations

So what can we learn from our experiences of curriculum development and implementation in developing countries? Looking at the 'wreckage', to use Konai Helu-Thaman's (1991) term, one might think that we have not learned very much at all. But we suggest here that a critical analysis of local experiences provides a sound platform for further development and implementation. The recommendations made here are derived from the above discussion.

Our first recommendation is that *curriculum development should be needs-based*. Although this might seem rather self-evident, curriculum development has seldom been based on a needs analysis of the specific educational context. Economic development, we suggest, is not necessarily the 'be all and end all' of curriculum reforms. Consider some contextualised examples. Africa is ravaged by HIV/AIDS, which is not unrelated to economic development. If a large proportion of a nation's young people suffer from potentially fatal illnesses such as HIV/AIDS, Jonathan Clark and Cedric Linder (2006) rightly note that this will exert a serious impact on economic development. But surely, as its first priority, science education in developing nations should be about health-related matters, such as HIV/AIDS prevention in Africa and sub-Saharan African nations, which Joseph Matsoga (2008) says is the major social issue; the water-borne diseases that are crucial in India, according to Mirdula Ranade (2008) and in Pakistan, according to Nelofa Halai (2008). Likewise, the notion that producing more science graduates will result in economic growth is, to us, too simplistic. Vanwyck Chkasanda and Ida Mbendera (2008) talk about the pointlessness of Malawi continuing to produce far more technical college graduates than the local manufacturing industry can ever employ.

Second, the literature suggests that the curricula enacted in developing nations are still dominated by external, foreign ideas (such as constructivism or learner-centred education). We are sympathetic to the notion of learning from others; it would be imprudent to ignore high-quality international educational research about teaching approaches that genuinely seem to improve teaching and learning. We also recognise the temptation of developing nations to adopt what appears to have been successful in developed nations. However, we suggest that *curriculum development and reform need to be built upon careful evaluation of past* local *experience*. This is not to say that we should ignore international ideas and trends, but we *must* tailor them to the peculiarities of the local context (Hsiung 2007). It is not unreasonable to decide after careful evaluation that we do not need to substantially reform our curriculum. As the case of Turkey exemplifies, repeated change is highly destabilising and likely to result in teachers ignoring any reforms and carrying on teaching in much the same way. It would be nonsensical effectively to ignore the enormously valuable, in-depth, local research about science education in Thailand conducted under the auspices of IPST, or the massive body of research conducted about science education in Taiwan.

Third, there needs to be *coherence between curriculum aims and assessment of learning outcomes*. Again, one might think that this is self-evident, but again we argue that it seldom actually occurs, especially in developing nations. If we want teachers to use learner-centred teaching approaches, we cannot expose them to ridicule or bad employment evaluations by retaining assessment regimes that are wholly inconsistent with such teaching approaches. This is what John Biggs (1992) refers to as 'constructive alignment': curriculum objectives and learning outcomes are duly aligned with methods of teaching and learning, which in turn are aligned with modes of assessment. The literature suggests that we need to employ multiple modes of assessment to be consistent with a learner-centred curriculum (Tobin and Tippins 1993; Wheatley 1991). Richard Coll and Neil Taylor (2008b) note that assessment regimes in developing nations are the principal drivers of teacher behaviour, and that no amount of professional development will bring about pedagogical change if summative assessment regimes are retained. There are promising indications that this connection is finally being made and that there are signs of constructive alignment in some nations. In Fiji, as mentioned above, major efforts are being made to link the assessment regime with intended learning outcomes (Taylor et al. 2008). Likewise, Princy Selvaruby et al. (2008) report a shift towards school-based assessment in Sri Lanka, which is something that they argue enables teachers to combine formative and summative assessment systems. Such change to assessment practices is often contentious, but Anne Hume (2003) argues this is often just because it takes time for all stakeholders to adjust to new assessment regimes, especially if they are radically different from those experienced in the past. Patience could be required to win over the sceptical!

Fourth, whilst we have argued above that teacher professional development will not, of itself, bring change to pedagogy or intended learning outcomes, *curriculum reform and subsequent implementation need to be accompanied by substantial and* ongoing *teacher professional development*. The logic here is deceptively simple; we can hardly expect teachers to change from a highly didactic teaching approach towards a more learner-centred education system if we fail to develop a shared understanding between teachers and curriculum developers of what learner-centred education actually means (Sade 2008; Varela 2007). We have good evidence of what does not work according to Chen-Yung Lin et al. (2005). Anthony Koosimile and Bob Prophet (2008) report that the cascade model, in which selected teachers receive training and then convey the message to their peers, has failed spectacularly in Botswana despite enormous resources being provided for implementation. Teacher professional development should be collaborative in nature, especially if new curricula involve new, imported or foreign ideas or theories. Bill Atweh et al. (2008) report a fascinating collaborative model for teacher professional development in the Philippines framed as 'capacity building'. The idea is not dissimilar to Koosimile and Prophet's (2008) cascade model, but differs in important ways. Key differences lie in 'minimizing the uncritical transfer of knowledge and value' (Atweh et al. 2008, p. 4), along with careful attention to the status attributed to the foreign expert and local curriculum developers or teachers. Atweh and colleagues remind us that the teacher is the principal mediator of curriculum implementation and that, unless we want implementation to 'fall at the last hurdle' (i.e. the classroom), we need to view teacher professional development as an integral part of the investment in curriculum development or reform, and not some additional cost towards the end of the process that Choshi Kasanda (2008) says occurs all too often. The alternative, noted by Ann Ryan (2008), is that science education is strongly influenced by neo-colonial influences that significantly contribute to the 'silencing' of the local voices. Implicit in this silencing is the notion of respect, something that Kathryn Scantlebury argues is all too often lacking in foreign experts' treatment of locals during curriculum development (Scantlebury 2008).

Fifth, and again one might think it obvious, *curriculum development and particularly effective implementation take time* and typically a lot longer than allowed. It is difficult to divorce the time element from the political dimension as the Turkey situation indicates. John Rogan and Diane Grayson (2003) report that curriculum implementation that was based on good ideas in South Africa failed because the newly elected government did not allow sufficient time for implementation of a curriculum. 'In Southern Africa in general, there appears to be a tendency to ignore existing diversity and to mandate complex and comprehensive changes in systems that may or may not be ready to cope with them' (Rogan and Grayson 2003, p. 1175). It is imprudent to expect effective implementation of a new or reformed curriculum in a few years, but our contention here is that this implementation should be a measured *incremental* process that is informed by evidence-based research and evaluation studies that are contextualised to the particular educational setting (Weinstsein 2008). John Rogan (2007) talks of the *zone of feasible innovation* and relates curriculum change to Vygotsky's zone of proximal development. We need to move into a 'curriculum space' that represents genuine advancement, but only at a pace that stakeholders can cope with. Research in China by Bangping Ding (2008) suggests that the central government was very measured in its approach to curriculum development. It first engaged in the development of a sound rationale for curriculum reform and subsequently it identified four distinct phases for curriculum implementation: alignment with modernisation; a study of future employment needs; raising quality in education; and considering the role of science in society and addressing environmental problems (Bing and Thomas 2006).

Conclusions

It is all too easy to become despondent if one reflects upon Konai Helu-Thaman's exasperation and feels that not much has changed. But we suggest that there are genuine signs that we have learned from the mistakes of the past. There are indications that the governments of many developing nations appreciate the importance of a concerted, consistent and holistic approach to curriculum development and implementation. Good-quality international research provides helpful ideas for implementation in the very different educational contexts that exist in developing countries. Our recommendations and Rogan's model provide a sound basis for a much more thoughtful and measured approach to curriculum development and implementation in developing countries. Naturally we would expect failure if we tried to teach students something very far from their zone of proximal development; unless we do likewise with curriculum development and implementation, we are doomed to repeat the mistakes of the past.

We make two concluding comments. First, a critical reader might feel that our recommendations are all very well in theory but impractical because of a lack of resources. We disagree. We suggest huge amounts of money have always been spent, often unwisely, on science curriculum development in developing nations by local governments and local and international NGOs and aid organisations. We would argue that the money needs to be better targeted (as suggested above), and its spending should take cognisance of local realities. Second, in some cases, development of a common core science curriculum might make sense. This might seem to conflict with our first conclusion, but the key emphasis here is on the common *core* curriculum. This could be supplemented with modules that cover specific local needs. As an illustration, in a study of primary science curriculum projects amongst Pacific Island countries, Neil Taylor et al. (2003) discovered considerable duplication of effort for island states with small populations and very limited economic resources. Based on this finding, Taylor et al. argued for a common core curriculum with optional modules to cater for local difference in, say, biodiversity or particular local issues such as phosphate mining in Nauru. Probably this would be much more cost-effective than the current individual approach that often results in rather sub-standard curriculum resources being produced.

A key feature of our analysis here is that it is largely based on literature and research reports produced by local people in developing nations. Our contention is that these reports provide valuable insights from people intimately involved in science curriculum development and implementation in developing nations. It would be both imprudent and arrogant to ignore their voices. Failure to do so risks repetition of past mistakes, resulting in highly predictable failure in the development and implementation of science curricula.

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Chapter 52
Curriculum Coherence and Learning Progressions

David Fortus and Joseph Krajcik

In the 1999 TIMSS science achievement test for grade 8 students, the USA was ranked 18th place out of 38 countries (National Institute for Education Statistics 2001). Sofia Kesidou and Jo Ellen Roseman (2002) reported on an evaluation of the major American middle school science textbooks that were in use around the time of this test. This report revealed that almost all the textbooks dealt with a very broad range of topics and did not focus on coherent age-appropriate learning goals. They were piecemeal and lacked coordination and consistency across time, topics, and disciplines. The key concepts were often buried among unrelated ideas, surrounded by inappropriate details. The curricula did not take into account students' prior knowledge and did not build on them in a systematic way that Marcia Linn and Bat Sheva Eylon (2006) claimed would allow students to progress from superficial to integrated understanding. By integrated understanding we mean ideas that are connected to each other in such a manner that allows learners to be aware of and be able to use relationships between various ideas to solve problems and understand the world they live in. Such understanding allows learners to use this relational network of ideas to explain and predict phenomena as well as solve problems.

In parallel, in a study of student learning as measured by TIMSS, William Schmidt et al. (2005) found that curricular coherence was the most dominant predictive factor of student performance. Similar to Schmidt et al., we describe curriculum coherence as the alignment of the specified ideas, the depth at which the ideas are studied, and the sequencing of the topics within each grade and across the grades.

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This analysis indicated that one of the likely reasons for the poor performance of the USA in the TIMSS exam was the incoherent nature of the textbooks used in American classrooms. It became clear that efforts to improve science education needed to consider how to design curricular material with a high degree of coherence.

Shortly afterwards, Mark Wilson and Meryl Berenthal (2006) raised the notion of learning progressions and Richard Duschl et al. (2007) reinforced it as a framework for designing curriculum and assessing student progress. Learning progressions are descriptions of successively more sophisticated ways of thinking about how learners develop key disciplinary concepts and practices within a grade level and across multiple grades. The underlying idea of learning progressions is that learning unfolds across time as students link previous ideas and experiences to new ideas and experiences. Learning progressions allow designers to bring coherence to their curriculum materials, coherence that is crucial in supporting student learning by providing alignment between standards, instructional tasks, and assessments across grades and grade bands.

As will become apparent in the following sections, there are actually different kinds of curricular coherence, some easier to obtain than others, but all are required outcomes of effective learning progressions. Attempts to develop coherent curriculum materials in the USA have been few and have typically focused on stand-alone units that do not provide the coherence between units, within and across years, that is one of the hallmarks of an effective learning progression that allows learners to develop integrated understandings. This chapter describes the different kinds of coherence, the difficulties involved in obtaining them, their relation with learning progressions, and the role that they all play in supporting student learning.

Different Kinds of Coherence

Content Standards Coherence

Schmidt et al. (2005) define content standards to be coherent if:

> … they are articulated over time as a sequence of topics and performances consistent with the logical and, if appropriate, hierarchical nature of the disciplinary content from which the subject-matter derives… They must evolve from particulars to deeper structures… This evolution should occur both over time within a particular grade level and as the student progresses across grades. (p. 528)

Hence, coherent content standards are likely to result in helping students to develop integrated knowledge that can be used to understanding phenomena.

The Atlas of Science Literacy of Project 2061 (AAAS 2007) presents an attempt to organize and sequence content standards to support the construction of deep and interconnected understanding of concepts. In many ways, the Atlas is like a huge, interconnected tapestry of Gagné-like knowledge hierarchies (Gagné 1966).

The Atlas is divided into many columns and four rows. Each column contains the concepts that are relevant to a particular strand of scientific thought or phenomena, for instance, mechanisms of biological inheritance, electric currents, or behavior at different scales. Each row contains concepts that are deemed appropriate to be learned in a specific grade band (K–2, 3–5, 6–8, and 9–12). Concepts that are logically or disciplinary dependent, are connected by arrows going from the basic one to the more advanced one. To promote the coherence of these maps, Jo Ellen Roseman and Mary Koppal (2008) report that Project 2061 attempted to include only those concepts that were considered central to their strands. While there is still a lack of evidence supporting many of the strands in the Atlas, this remains perhaps the most detailed and comprehensive example of content standard coherence.

Unfortunately, many states have not followed this example when crafting their own standards. State standards are often incoherent, too vague to be useful, and inaccurate (American Federation of Teachers 2003; Gross et al. 2005). This lack of content standard coherence and the large variability between the standards set by different states presents considerable challenges to curriculum developers and publishers and is undoubtedly one of the reasons for the poor state of US science textbooks (Roseman and Koppal 2008) and student achievement on tests of international comparison.

Learning Goals Coherence

One of the first decisions designers of instructional materials need to consider, whether they are developing a unit that deals with a single topic or materials that span several years of study and cover multiple topics and science domains, is what will be the learning goals of the curriculum. Creating a coherent set of learning goals is a crucial step in the design process. As Yael Shwartz et al. (2008) pointed out, learning goals should be the foundation of any curriculum; if they do not comprise a coherent set, anything built upon them will be shaky at the best.

Although learning goals are based on content standards, some important differences exist between them. The first difference is in their number – there are many content standards, so many that many researchers and curriculum designers think there are too many (Duschl et al. 2007). On the other hand, learning goals need to be limited in number to allow the designers and teachers to deal with them in satisfactory depth over the time allotted to the curriculum. We believe that just presenting ideas to students is not the same as engaging them in learning the ideas so that they build understanding. Too many learning goals lead to superficial coverage and little conceptual understanding in students. So once the focus of a unit is decided, the designers need to choose which content standards are age-appropriate and relevant to this topic. The relevant content standards will most likely be drawn from multiple strands in the Atlas (AAAS 2007) or another standards document. Often the number of standards that meet these requirements is still too large. What criteria should be used to pare down the number of content standards and how are these then linked to create a set that is coherent in the sense described by Jerome Bruner (1995, p. 334): "[giving the student] the experience of going from a primitive and weak grasp of some subject to a stage in which he has a more refined and powerful grasp of it"? Such a process will allow learners to develop a rich understanding of the concepts as the unit progresses.

This is where the relation between coherence and learning progressions first appears. As mentioned previously, learning progressions are research-based descriptions of successively more sophisticated ways of how learners develop key disciplinary concepts and scientific practices across time. Learning progressions can provide the framework to help designers decide which learning goals are critical to a topic, which are secondary and, which are not essential, and how these learning goals need to be sequenced to provide coherence. Of course, learning progressions need to be empirically tested using coherent curriculum. As such, the design of learning progressions and coherent curricula is an iterative process. The empirical work that results from validating learning progressions can provide evidence to support or indicate the need to revise the sequencing and organization of many of the strands in the Atlas.

A learning progression typically organizes concepts from particulars to deeper and more integrated structures. For example, the idea that objects appear to have different colors because they absorb and scatter different wavelengths of visible light is based on the idea that light scattered from an object needs to enter our eyes for the object to be seen. So it would be expected that a learning progression about the role of light in sight would place the idea that "light from an object needs to enter our eyes for the object to be seen" before the idea "different colored objects scatter different wavelengths of light" (AAAS 2007, p. 67).

However, since the study of learning progressions is a relatively young field of research and development, there are only a handful of existing learning progressions, and even fewer that have been fully articulated and tested (Catley et al. 2005; Directorate for Education and Human Resources 2005). So most likely, designers will not be able to use a learning progression as a ready-made artifact in supporting learning goal coherence. Instead, designers need to use a hypothetical learning progression, which describes a theoretical model for successively more sophisticated ways of thinking about the ideas for which they are designing curriculum but which have not been validated with empirical evidence, and use this as a first guess in selecting and organizing their unit's learning goals. Later on, data collected once the unit is completed and enacted in multiple sites, can serve as evidence confirming or disconfirming aspects of the learning progression (Smith et al. 2006). Thus, the process of using learning progressions to construct coherent learning goals that are the foundations for units is also the process by which the learning progressions are validated.

A second difference between learning goals and content standards is their specificity. As Joseph Krajcik et al. (2008) demonstrated, each content standard can involve multiple ideas that need to be separated, unpacked, and clarified as to how the designers intend to operationalize them. For example, this is how we unpacked a content standard:

> Content Standard: Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection). To see an object, light from that object – emitted or scattered from it – must enter the eye.
>
> Unpacked Content Standard: Students should recognize that these are the three basic ways in which light interacts with matter, and they should be able to distinguish between the three by classifying their observations of phenomena. Students should be able to relate the thickness, surface features, and opacity of an object to its ability to scatter, transmit, and absorb light. Students should be able to explain how the color of light transmitted or scattered by an object depends on the object's color (as perceived when illuminated by white light) and the color of the illuminating light, but they should not be expected to explain why certain colors/wavelengths are absorbed while others are scattered or transmitted.
>
> Students need not understand that scattered or transmitted light is actually the result of absorbed light that is re-emitted. We will deal with absorption, scattering, and transmission as three different phenomenological categories that provide a useful way of classifying certain phenomena.
>
> Students should understand that light that is not scattered or transmitted, must be absorbed. While we will not deal explicitly with the notion of conservation, we wish to plant a seed about conservation that will be returned to and reaped in the 7th grade energy unit.
>
> Reflection and refraction are phenomena that represent specific ways in which light can be scattered or transmitted by an object. They are specific because they describe how individual light rays are redirected when they come into contact with specific objects, rather than providing a general description of how the light interacts with matter. We will discuss the difference between scattering and reflection from planar mirrors, but will not investigate refraction. We will deal with the law of reflection.
>
> We will not explore how the redirection of light changes how an object appears to the eye. (Fortus et al. 2006, p. vi)

Note that this elaboration mentions not only what will be done, but also what will not. It also mentions how a particular idea will serve as the seed for a different idea in a different unit (see section on "Interunit coherence").

The final difference between content standards and learning goals is that learning goals specify not only what students should know; they also specify what students should be able to do with their knowledge. This is a variation on David Perkins' (1992) "understanding performances."

For example, the unpacked content standard about light described earlier and an unpacked standard about scientific modeling "models are used to illustrate, explain or predict phenomena" can be combined to make the following learning goal: "Ss use a model of light to explain why it is possible to see through some objects but not others" (Fortus et al. 2006, p. 172). Figures 52.1 and 52.2 illustrate this process. The same unpacked content standard can be combined with different practices at different places along a unit, as appropriate.

To summarize, a coherent set of learning goals is composed of a relatively small number of content standards, each unpacked to describe how it will be operationalized in the curriculum, organized to go from simpler to more complex levels of understanding, and specifying what students should be able to do with this knowledge.

Fig. 52.1 Learning goals

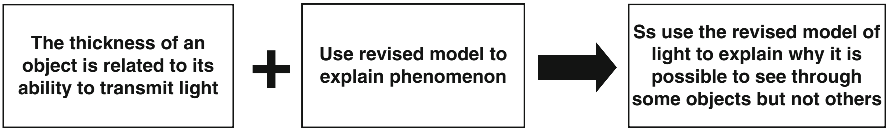

Fig. 52.2 A specific learning goal

Intra-unit Coherence

Intra-unit coherence results from the coordination between content learning goals, scientific practices, inquiry tasks, and assessments within a project-based framework. A coherent unit can be thought of as a four-dimensional entity, with a progression occurring along each dimension: content learning goals, scientific practices, inquiry tasks, and assessments. While designing the progression along any one of these dimensions is not a simple task, coordinating between all three progressions is very difficult and involves multiple design iterations. The former section described the characteristics of a coherent set of learning goals. The next three sections do the same for the other three dimensions and show how these dimensions can be intertwined.

Coherence of Scientific Practices

As elaborated by Helen Longino (1990), Nancy Nersessian (2005), Richard Lehrer, and Leona Schauble (2006), scientific practices represent the disciplinary norms of scientists as they construct, evaluate, communicate, and reason with scientific knowledge. As adapted to the classroom, scientific practices characterize how students use scientific understandings to make sense of and explain the world. Practices are important in science education for two complementary but distinct reasons: firstly, engaging in scientific practices is a means to engage learners in developing and using conceptual understanding; secondly, scientific practices define an important part of what it means to understand the discipline of science itself. As such, developing understanding of scientific practices can also be seen as a key learning goal.

There are many scientific practices, such as scientific modeling, constructing scientific explanations, designing experiments, and organizing and analyzing data that should be integrated into science education. However, just as with the content standards, there are too many elements to each practice to focus on them all together at the same time. Choosing which scientific practice to develop in a unit, on which elements of the practice to focus, and how to organize them in a coherent manner is as important a process as deciding how to obtain content learning goal coherence, and is done in much the same manner. Certain topics lend themselves to certain practices more than others. For example, the particle nature of matter is an excellent topic to engage in modeling because students can develop more sophisticated models of the nature of matter as they attempt to explain more phenomena. Evolution is not a good topic to engage in the design of experiments because of time constraints. Once the focal scientific practices for a unit are decided upon, the Atlas (AAAS 2007) or other coherent standards and a learning progression are used to identify the age-appropriate elements of the practices and organize them in a coherent manner. Due to the paucity of validated learning progressions, especially progressions of scientific practices (Directorate for Education and Human Resources 2005), there will be much uncertainty in how the scientific practice develops over time. Also, because of the interplay between content understanding and the understanding of scientific practices, it is unclear how understanding of practices in one area of understanding will influence understanding of the practices in other content areas. However, tentative work by Yael Bamberger and Elizabeth Davis (2011) and David Fortus et al. (2010) does indicate that the features of some practices may transfer from one content area to another.

Inquiry Sequence

What can a curriculum designer do to maintain student interest and engagement while inquiring into a topic that, off-hand, may not be not seem interesting to them at all, such as the interaction between light and matter or the particle nature of matter? Joseph Krajcik and Phyllis Blumenfeld (2006) indicate that many researchers have found that a driving question can serve to motivate students and maintain their interest over prolonged periods. Learners, however, need to be shown the value of driving question. One way this is done is by engaging students in anchoring phenomena. How is this done? Through attempts to explain the phenomena, students become engaged in formulating a scientifically accurate answer to the driving question. Since the driving question typically deals with a complex, nontrivial issue, the process of answering it will require several steps, some of which can be done in parallel because there is no concept dependency between them, while some depend on the results of other steps, using their outputs as inputs. This process can be seen as a progression toward the resolution of the driving question; each step adds detail and potentially combines different pieces of the answer into a larger, more complex entity, bringing us closer to full resolution of the question. It is important to realize that most learners will not see meaning in the driving question unless they experience the phenomena and see the relevance of the question to their lives (Krajcik and Blumenfeld 2006). For this reason, rather than phrase driving questions as topic-oriented questions, such as "What is the structure of matter?" they should be phrased as phenomenon-driven questions for which students can develop meaning, such as "How can I smell things from across the room?"

The steps to the answer of the driving question are mapped onto the learning goals of the unit. The organization of the learning goals, as dictated by a learning progression, will not always match the sequence of steps in answering the driving question. Not all the learning goals may be relevant to the answer to the driving question. Usually, the sequence of steps in answering the driving question can be reorganized to provide closer alignment with the coherent set of learning goals. At other times, the coherence requirement of the learning goals maybe so off that the driving question may need to be revised. Of course, as with any true scientific inquiry, one can make detours to ensure that prior knowledge is activated or to wander beyond the minimum requirements to respond to student interests. At the end of this process of choosing a driving question, analyzing its answer and mapping it onto the learning goals, the scope and sequence for the unit should be fully articulated: the unit will follow the path described by the answer to the driving question, with the various steps on the way aligned with different learning so that at the end of the unit, all the learning goals will have been covered. Shwartz et al. (2008) provide a few examples of how this was done in units dealing with the nature of light and the particle nature of matter.

Coherence of Assessments

Teachers and students need a feedback mechanism that will allow students to learn how they have progressed and where understanding impediments remain. Coherent assessments are embedded in a unit in a timely and ongoing manner, and they are aligned with the learning goals and the level of understanding that can be expected at different points in a unit; otherwise, the information they provide is dramatically less useful in supporting learning and teaching.

Coherent assessments should come in different forms – a discussion question, a homework task, the construction of a model, the analysis of data, a quiz. The assessments should be placed in strategic locations throughout the unit, places where the students have presumably already learned something about the learning goals addressed by the unit, but not too late so that there do not remain any other opportunities to rectify any difficulties that the assessment may uncover.

Each assessment opportunity should explicitly point out to the teachers why it is located where it is and what to do with possible student responses. For example, in a unit on light, after students have encountered the ray model of light, the different ways light interacts with matter, that light from an object needs to enter the eye for the object to be seen, and the relation between perceived brightness and the amount of light entering the eye, the following series of question could serve as an assessment of the understanding of these ideas. Note that the questions include information for the teacher regarding what to look for in students' responses, why the questions are located where they are in the unit, and what to do if students are having difficulty responding to the questions (Fortus et al. 2006, p. 278):

> By this time Ss should be able to explain that some scattered light from an object needs to enter their eyes for the object to be seen. The next section builds off this learning goal, distinguishing between different colors of light. These are some questions will elicit students' understanding of this learning goal while setting the stage for the next activity, which involves mixing different colors of light on a screen.
>
> - Can you see the screen when the projector is off? Why or why not?
>   *Yes. Students should mention that light from outside is being scattered by the screen. Some of the scattered light is moving to their eyes.*
>   Turn on an overhead projector.
> - How does the screen look different now than it did before?
>   *The screen looks brighter.*
> - Why is the screen brighter?
>   *It is important that Ss be able to explain that more light is reaching the screen, since it is now illuminated by the projector AND by light from outside. Since more light is reaching it, more light is being scattered by it, so more light from the screen is reaching their eyes. When more light enters their eyes, they interpret whatever is being seen as being brighter.*
>   If Ss struggle to respond, you can place a transparency with the light model on the overhead projector and ask the following question.
> - If the screen is the object being seen in the model, what happens when more light is directed at the object?

There should be a progression in the assessments along the unit so that assessments that come later in a unit involve deeper understanding and target multiple, rather than single learning goals and practices.

Interunit Coherence

Interunit coherence is similar to intra-unit coherence, except that it relates to larger inquiry sequences, multiple scientific practices, and different content domains within and across years. Interunit coherence deals with the question of how to coordinate among units to support the development of content and practice learning goals across a year of instruction or across several years of instruction, so that learners build a deeper and integrated understanding of core ideas. While several units, mainly ones funded by NSF, have been crafted that attempted to achieve learning goal coherence and/or a coherent inquiry sequence, fewer have attempted to be coherent with respect to scientific practices. Almost none have attempted to achieve interunit coherence, for the simple reason that they were typically developed as stand-alone entities, not part of a coherent and comprehensive curriculum.

A coherent sequence of units is comprised of individual units, each one of which is independently coherent, but which are subjected to additional constraints and requirements, that allow them to build off one another, for ideas to flow from one to the others, and for the students to reach a higher degree of knowledge integration

(Roseman et al. 2008) than would have been possible than if the units were truly stand-alone entities, with no explicit connections between them.

Learning progressions are central to designing for interunit coherence, even more so than for intra-unit coherence. As stated earlier in this chapter, learning progressions are descriptions of successively more sophisticated ways of thinking about how learners develop key disciplinary ideas and practices across multiple grades. A single unit does not span multiple grades nor does a unit deal with multi-interdisciplinary ideas and practices. Thus, while the design of a coherent unit draws upon a learning progression to determine the sequencing of and connections between learning goals of the unit, this is only the beginning of what learning progressions have to offer. The real power of learning progressions is that they look at the development of ideas over prolonged periods of time, much beyond the scope of a single unit. Developing interunit coherence will require the integration of several learning progressions.

A single unit might draw upon two learning progressions – one for its content learning goals, the other for its central scientific practice. On the other hand, a curriculum that has interunit coherence must draw upon multiple learning progressions, one for each key disciplinary idea and one for each scientific practice. It is likely that these learning progressions were developed independently of each other, so the designers of coherent curricula face the task of figuring out how to conjoin these together.

To describe how this can be done, we use the example of a learning progression for the idea *matter and energy are transferred between organisms and their environment* and show how it was implemented in a curriculum developed by Joseph Krajcik et al. (2001, 2004) called IQWST (pronounced I-Quest) – Investigating and Questioning our World through Science and Technology – through grade levels and across disciplines, in multiple units, each of which provides a necessary element of this idea (Shwartz et al. 2008, p. 214). Table 52.1 identifies the various content standards from the Atlas (AAAS 2007) and their sequencing in the curriculum needed to support understanding of this key idea.

This progression of the ideas is not linear. It provides opportunities to revisit, enhance, build further, and apply knowledge in different disciplinary units and grades to construct integrated knowledge of the transformations of matter and energy in ecosystems and create a powerful view of explaining the world. The same key ideas are often addressed in different units, at different levels of sophistication, and highlighting different aspects. An important component of any learning progression is not just specifying the knowledge but also how the knowledge is used. For example, in the 6th-grade biology unit, students determine that food is made of carbohydrates, proteins, and fats, and provides energy and building materials for all living things. Students use these ideas to explain why they need to eat in order to grow and stay alive. The 8th-grade chemistry unit revisits this idea and investigates the molecular structure of these substances, concluding that they are complex molecules that explain ideas related to photosynthesis and respiration. Explicit links to ideas learned in other places are made throughout. Such interunit coherence ensures that the key ideas are not just dealt with for a short time: they stay in the curriculum

Table 52.1 Sequencing of standards across the curriculum to support a key idea

Key idea	Where it is addressed
All matter is made up of atoms	6th-grade chemistry
Food provides the fuel and the building material for all organisms. Plants use the energy in light to make sugars out of carbon dioxide and water	6th-grade biology – macroscopic perspective 8th-grade chemistry – molecular level
Atoms that make up the molecules of existing substances rearrange to form new molecules of new substances	7th-grade chemistry
Conservation of matter in a chemical reaction	7th-grade chemistry
Energy transformations and conservation in living things	7th-grade physics
Animals get energy from oxidizing their food, releasing some of its energy as heat	8th-grade chemistry – oxidation reactions
Food energy comes originally from sunlight	6th-grade biology 7th-grade physics – energy from the sun 8th-grade chemistry – photosynthesis
Matter and energy are transferred from one organism to another repeatedly and between organisms and their physical environment	6th-grade biology – food chains 8th-grade chemistry – cellular respiration and photosynthesis

and are revisited repeatedly from different points of view. This helps students make connections and gradually build an integrated knowledge of the key ideas.

At the same time, another learning progression involving the particle nature of matter is developing in these same units. The key idea that matter is made of particles is first introduced in the 6th-grade chemistry unit where students use these ideas to explain why objects can be smelled from across a room. The 6th-grade earth science unit uses the particle model to explain the water cycle. The 6th-grade biology unit uses this idea to discuss processes in living systems. The 7th-grade physics unit uses it in investigating and explaining thermal, chemical, and electrical energy. The 7th- and 8th-grade chemistry units use it in investigating the chemical reactions involved in photosynthesis and cellular respiration.

This approach is different than that found in traditional noncoherent curricula or in what has been called spiral curricula. It emphasizes that real-world phenomena are complex, the knowledge needed to make sense of them is not limited to a single discipline, and that understanding unfolds over time. In a traditional curriculum, photosynthesis will usually be presented as a topic in biology. The molecular aspects of the process, as well as understanding its importance in transforming light energy into chemical energy are not emphasized. Few middle school chemistry and physics curricula actually deal with the different aspects of photosynthesis (Schmidt et al. 2005). It is different from spiral curricula because ideas are dealt with in more sophisticated manners from multiple disciplinary perspectives to explain more complex phenomena.

A coherent curriculum should be more than just a tool that sequences tasks, learning goals, and scientific practices in a coherent manner. It should also be coherent with respect to the language it uses and the teacher support it provides.

Language Coherence

Every scientific concept and practice is accompanied by a multitude of disciplinary terms that are used by scientists when communicating with each other about these concepts. While students should not be expected to learn convoluted terms for the sake of knowing them, certain terms are central to scientific discourse on certain topics, and any omission of them will hinder the ability to freely communicate with these ideas. For instance, when learning about energy, the terms "conservation," "transformation," and "transfer" are key terms that students need to learn, because almost any scientific discourse on this topic will use them. Moreover, having fluency of these ideas allows learners to explain a host of phenomena that they experience in their lives.

On the other hand, often the same terms have very different meanings in the different science disciplines. For example, biologists often say that energy is used by an organism. For physicists, energy is never used; it is transformed or transferred. They would say that biologists are really talking about "free energy" or the "Gibbs function." In another example, a system for biologists and earth scientists is a collection of components that together lead to complex phenomena. Chemists and physicists often speak of systems as anything within boundaries, real, or imaginary, that can be analyzed separately from their surroundings.

While the same terms often have different meaning, the opposite is often true too – different terms are often used as though they have the same meaning, leading to confusion as to why there needs to be multiple terms at all. For example, predict and hypothesize are often used interchangeably, even though there is a difference in their precise meaning. Information, data, and evidence are also very closely related, and are often used synonymously, even though they really do not mean the same thing.

Misunderstandings are guaranteed if the same word is used differently in different contexts or if different words are used as if they had the same meaning, especially with younger students. In coherent curricula it is important either to use terms in a consistent manner across all contexts or to explicitly clarify the different meanings the terms have in different places, why they are used in one place in one way and a different way in another place.

Coherent Teacher Support

Ever since Deborah Ball and David Cohen (1992) suggested the potential curriculum material could have in supporting not only student learning but teacher learning as well and Betsy Davis and Joseph Krajcik (2005) laid out design heuristics to realize this potential, educative features have become a standard characteristic of all high-quality curriculum materials. It is not enough for a coherent curriculum to include these features; these features themselves must be organized in a coherent manner, one that supports growth in teacher knowledge in a way that matches the other coherent features of the curriculum.

Most likely because of the education science teachers experienced and the manner in which most science textbooks are written, many teachers do not have a developmental perspective on how to help students learn ideas across time. As such, many teachers do not see the need to develop ideas across time. An educative curriculum that provides commentary, teaching ideas, and various supports is essential in helping teachers learn how to teach in a more developmental fashion. For instance, linking ideas within a unit and across units is a critical feature in teaching in a developmental manner, as it builds upon the prior knowledge of learners. In a coherent curriculum, the curriculum developers should frequently point out connections to related ideas developed in previous units and suggest how to relate these ideas back to students. Such a process allows students to develop integrated knowledge rather than isolated understandings.

Conclusions

As the world becomes ever flatter (Friedman 2007), with nations becoming more diversified, the challenge of how to provide quality science instruction is more amplified than ever. Today's children are growing up in a world where they will need to apply and communicate ideas, make sound decisions based on evidence, and collaborate with others to solve problems, activities that require a deep and interconnected understanding of the fundamental ideas underlying these problems. Yet, most of our schools do not have this focus and their teachers still use curriculum materials that lack any support for students to build ideas across time. Too many schools still try to cover too much content without focusing on developing deep, integrated understanding.

As described above, learning progressions are descriptions of successively more sophisticated ways of thinking about how learners develop key disciplinary concepts and practices within a grade level and across multiple grades. The underlying idea of learning progressions is that learning unfolds as students link previous ideas and experiences to new ideas and experiences. Learning progressions are essential in designing materials that have learning-goals, and intra-unit and interunit coherence – materials that can allow learners to develop integrated understandings of key scientific ideas and practices across time. However, much work needs to be done to design coherent curricula, validate learning progressions, and then redesign both the materials and the learning progressions.

At present, in the USA there is no curriculum built in this manner. Existing US curriculum has students experience ideas in a piecemeal fashion, leaving them with a superficial understanding of isolated ideas and not seeing how these ideas relate to one another. Curriculum materials that are based upon learning progressions need to be designed, implemented, and tested. Such empirical work will feedback into modifying the learning progressions. As mention earlier, each state has their own standards and often these standards are not coherent. It might be possible for each state to develop their own coherent materials, but such a process is too time- and resource-intensive for individual states (Roseman and Koppal 2008). The development of coherent curriculum materials calls for multiple cycles of design and development, testing and revising the materials, aligning materials, assessments, and teacher support with learning progressions. This requires substantial resources. Although the investment is substantial, the potential outcome of a generation of scientifically literate children is well worth the effort.

IQWST (Krajcik et al. 2001, 2004) is an example of a work in process that is attempting to rectify this situation by building coherence within and across units in a middle school science curriculum. These materials need to be tested to verify that this intense development work actually makes a difference and does lead to a more integrated understanding. But to do so requires that the materials be used by teachers as intended by the designers. This does not mean that the materials need to be scripted, but it will require intense professional development and educative features to help teachers use the materials as intended. The IQWST work is supporting and being supported by the development and validation of several learning progressions that will involve further iterations. Some of this work has started but more is still needed (Merritt et al. 2008; Schwarz et al. 2010).

Because of the overabundance of standards, teachers feel pressure to cover many topics, fearing that they will appear on high-stakes examinations. Yet, it is known that mere coverage of material does not lead to integrated understanding of ideas. Learners need to experience science in engaging contexts and apply ideas in order to learn. Yet with so many standards, teachers feel as if they must cover many topics. Many teachers did not learn science themselves in a developmental manner in which ideas built upon each other, where evidence was used to support claims and where science ideas were used to explain important problems and phenomena; as such, there is a need for educative resources and intense professional development that can support teachers in the use of coherent curriculum materials that can promote the constructing of an integrated knowledge of fundamental science ideas. Testing of coherent curriculum built on learning progressions could provide the evidence to show teachers and policy makers that learning ideas in depth actually supports science literacy more than just the covering of materials.

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Chapter 53
Socio-scientific Issues in Science Education: Contexts for the Promotion of Key Learning Outcomes

Troy D. Sadler and Vaille Dawson

Throughout the history of science education, scholars and practitioners have called for the contextualization of science content through the exploration of socially relevant issues. Over time, responses to these calls have varied from pockets of acceptance and implementation to outright rejection because of a perceived need to return to basics (DeBoer 1991). The Science-Technology-Society (STS) movement, originally established in the 1970s, has been the most widespread and recognizable movement within science education for prioritizing the social significance of science. By the time of publication of the first edition of the *International Handbook of Science Education* (Fraser and Tobin 1998), STS was a well-established trend in school systems and research programs across the globe. Although STS was not the primary focus of a chapter in the first edition, STS themes were represented in several chapters throughout the volume (at least 12 of 72 chapters).

In the 10 years since the publication of the *International Handbook*'s first edition, a new framework has emerged for teaching and research associated with socially relevant science: socio-scientific issues (SSI). The phrase socio-scientific issues was used in the science education literature as early as 1986 (Fleming 1986), but it did not come to represent a recognizable framework for research and practice until the late 1990s. Research originating from countries around the world has helped to shape this movement. Dana Zeidler, Troy Sadler, Michael Simmons, and Elaine Howes have argued that the SSI movement marks an advancement over previous efforts to feature socially relevant issues in science education because of explicit grounding in theory

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(Zeidler et al. 2005). More specifically, much of the SSI research has been based on theory derived from cognitive and developmental psychology. More recently, researchers exploring SSI have adopted sociocultural theories and situated learning perspectives to inform and shape their work (Sadler 2009).

Much of the early work related to SSI has focused on learner practices in the context of socio-scientific controversy. For example, researchers have explored how students negotiate information provided in reference to SSI, engage in argumentation regarding SSI, conceptualize the nature of science in the context of SSI, and apply science content knowledge in the negotiation of SSI. The first author reviewed and synthesized a subset of this work in an earlier report that offers an empirical analysis of informal reasoning practices in the context of SSI (Sadler 2004). This analysis informs questions related to how learners react to, negotiate, and resolve SSI, but it does not directly address questions related to the use of SSI as contexts for learning. Several SSI researchers and advocates have argued that SSI can and ought to be used as contexts for learning science. They suggest that contemporary social issues with conceptual ties to science can serve as a basis for student understandings of science and nature of science, generate interest and motivation for learning science, and support development of argumentation practices. The focus of this chapter is reviewing and synthesizing evidence amassed through investigations of these learning outcomes in the context of SSI-based education.

Our aim is to explore the effectiveness of SSI as contexts for science education. Advocates have written about the potential of SSI-based education for positively impacting desirable learning goals. Here, we will review reports that have put these ideas and assumptions to test through empirical investigation of learning outcomes associated with SSI-based educational interventions. This chapter does not provide a fully comprehensive summary of all research related to SSI; rather, our intent is to describe and synthesize a focused sample of research that illuminates student learning associated with several widely assumed goals for science education: science content knowledge, nature of science, interest and motivation, and argumentation.

In order to identify relevant literature for inclusion in this review, we established several criteria for guiding the selection of studies to be featured in this chapter. We sought reports that: (1) focused on SSI, (2) were empirical in nature, (3) involved the study of interventions, (4) focused on outcome variables of interest, and (5) met standard expectations for rigor. Although we support the shift toward the theoretically oriented SSI framework, we acknowledge that strong work related to socially relevant issues is carried out using various labels. Therefore, we considered studies that used several different names to indicate their focus on socially relevant issues with connections to science including SSI, science–technology–society-, and context-based. We included papers that addressed research questions through the analysis of empirical data, and purposefully sought reports drawing on diverse methods and perspectives. We prioritized research that focused on the effects of SSI-based interventions on specific learning outcomes that have been consistently highlighted as significant issues for science education and likely targets of SSI education (i.e., science content knowledge, nature of science, interest and motivation, and argumentation). Finally, we made selective decisions based on the quality and rigor of research presented.

Content Knowledge

A chief goal for most science educators is student development of science content understandings. SSI advocates have argued that SSI can provide learning opportunities that promote the development of sophisticated ideas about science. Yehudit Dori et al. (2003) investigated this claim in the context of an SSI module that featured biotechnology in eight Israeli schools. Students completed pre/post assessments of their understandings of biotechnology concepts. The researchers grouped students by academic ability levels (high, intermediate, and low) for the analyses. Test results indicated a large and statistically significant gain (effect size = 2.27) across all three groups. The percentage gain was more pronounced for the low ability group followed by the intermediate and high groups. The authors suggested that this result highlighted the potential of SSI-related curricula as a means of reducing achievement gaps among diverse students.

Stuart Yager et al. (2006) also assessed content knowledge gains for students involved in an SSI-related intervention. The researchers created case studies of two middle school teachers in the USA. Over the course of a semester, one teacher structured her classes around exploration of a local STS issue (i.e., determining the site for a new landfill). Her colleague followed the standard science curriculum. Students in both classes completed pre/post content tests, and both groups demonstrated large gains that were statistically significant. Differences between groups were not statistically significant. Students in both classes learned science content, but neither approach produced demonstrably different results.

Grady Venville and Vaille Dawson (2010) explored science content learning among secondary students participating in an SSI intervention in Australia. They worked with a teacher, who implemented lessons related to genetic technologies and explicitly addressed argumentation practices. Intervention students ($n = 46$) completed pre/posttests for conceptual understanding of genetics. A comparison group ($n = 46$) that studied the same genetics topic without participating in argumentation and SSI activities also completed the assessments. Repeated measures ANOVA indicated that intervention students scored statistically significantly higher on the test of genetics content than comparison students. From a practical perspective, the authors classified the gains as modest but significant.

Rather than using a pretest–posttest design, Astrid Bulte et al. (2006) used a criterion-based model in their research. This design-based research project, conducted in the Netherlands, involved three iterations of curriculum design, implementation, and assessment. The evolving unit focused on water quality issues as a context for chemistry learning. A variety of data sources were used including video analyses of lesson enactment, field notes, teacher interviews, and student surveys. In the final iteration of unit enactments, the researchers concluded that large proportions of participating students ($n = 22$) demonstrated adequate understandings of the following knowledge categories: content knowledge related to the unit (80%), parameters for evaluating and interpreting water quality (70%), and experimental design (60%). The authors also concluded that by the final iteration, the unit sufficiently generated a need-to-know among students, that is, the experiences had successfully used context to stimulate students to a critical point of recognizing and embracing a need to know more about the science content underlying the issue.

Anat Zohar and Flora Nemet (2002) conducted an intervention study in two Israeli junior high schools. They compared student learning in response to a genetic engineering unit with an explicit focus on argumentation as well as a more traditional unit that covered the same genetics content; 99 students in five classes followed the SSI-related intervention, and 87 students in four classes followed a traditional curriculum. The researchers administered a test of genetics knowledge following unit implementation. Students in the SSI-related intervention performed statistically significantly better than the comparison students. Comparison of the raw scores indicates that the difference was practically significant as well.

The results discussed thus far provide evidence that students involved in SSI-related interventions can learn science content, but most of the content assessments related closely to the interventions. Two other reports, both conducted in the USA, documented these kinds of gains associated with SSI instructional units, but the researchers also administered more distanced assessments that were not directly aligned with the curricula. The authors argued that this approach provided a more valid tool for answering the question of how the interventions affected general knowledge structures not specifically tied to the interventions. In one study, students did not demonstrate statistically significant gains on the distanced test (Barab et al. 2007). In the other, researchers documented statistically significant changes with a moderate effect size (Klosterman and Sadler 2010). This result suggested that students developed understandings of science content as applied to the specific context of the intervention as well as in more generalized forms as would be expected on standardized tests.

Salters Advanced Chemistry (SAC) is a secondary science course developed in the UK that prioritizes the contextualization of chemistry and is consistent with an SSI approach. Barber (2001) investigated content learning of students participating in SAC and comparison students, who had completed traditional chemistry classes, through the use of a distanced test. The comparison students performed statistically significantly better than the SAC students. In discussing these results, Barber suggested that the test better reflected the focus and approach of more traditional chemistry courses. Although the SAC students did not perform as well as their peers, Barber reported that the SAC students outperformed their peers in university-level science courses.

Nature of Science

Several authors have proposed relationships between individuals' understandings of the nature of science (NOS) and their SSI decision-making, but few have investigated SSI as contexts for learning about NOS. Rola Khishfe and Norm Lederman (2006) explored NOS learning outcomes associated with a 6-week SSI intervention. Two classes received explicit NOS instruction, but for one class, NOS instruction was related to the issue of global warming. The researchers assessed pre- and post-intervention understandings of NOS by means of an open-ended questionnaire and student interviews. Results indicated that students in both groups made gains in their NOS understandings (related to NOS tenets such as creative, empirical, tentative). The authors reported some slight differences in the patterns that emerged in the two groups, but there was no indication that either setting provided an inherently better learning context for promoting sophisticated ideas about NOS.

Kim Walker and Dana Zeidler (2007) also investigated student development of NOS understandings in the context of an SSI-related intervention in a US high school. Walker and Zeidler designed a curriculum based on genetically modified foods such that NOS themes were highlighted and that assessment of NOS ideas was embedded in the learning activities. The authors concluded that students developed NOS ideas particularly in the areas of the tentative/developmental and creative/subjective aspects of science. However, when presented with an opportunity to apply these understandings (i.e., an SSI debate), students did not invoke NOS ideas. Walker and Zeidler concluded that the SSI-based unit promoted exploration of NOS ideas and some learning gains but that students ultimately did not develop robust enough frameworks for NOS to apply these ideas in more general decision-making opportunities.

Investigations of NOS are fundamentally about epistemology in that they deal with the nature of scientific knowledge and the generation of that knowledge. One other study explored epistemology but employed a more general framework as compared to typical NOS investigations. Dana Zeidler et al. (2009) studied the effects of a year-long SSI-driven intervention on reflective judgment, a construct that represents epistemological development. This research was situated in four US high school anatomy and physiology classes (two intervention and two comparison classes). The researchers collected and analyzed interview data using standard procedures for assessing reflective judgment (including qualitative and statistical analyses). Whereas students in the comparison classes demonstrated no changes in reflective judgment, students in the intervention classes demonstrated qualitatively and quantitatively significant differences over the year. The researchers concluded that prolonged and continuous opportunities to explore a variety of SSI over the course of an academic year likely stimulated epistemological development within this sample of students.

Interest and Motivation

A common claim advanced by SSI advocates is that students will be more interested and motivated to learn when science is presented in socially relevant contexts (i.e., SSI). Several reports have explored this assumption. Yehudit Dori et al. (2003) investigated student interest in SSI-based learning experiences in their study of a biotechnology module. The module prioritized and highlighted the controversial and ethically contentious aspects of genetics issues. The authors suggested that the explicit focus on controversial aspects of SSI is essential for building student interest. Students created porfolios, and 96% of the students (n = 200) explicitly discussed their interest in biotechnology. Many of these students referred to the personal and/or global relevance of these issues and actively petitioned to see more examples of science embedded in social problems.

Astrid Bulte et al. (2006) reported similar findings in their design-based, SSI research project. They concluded that as the unit was modified to make instruction driven more by the issue (as opposed to more traditional approach of science content driving instruction), learning activities became more meaningful to students, and that students became more engaged learners. Student survey data supported these claims in that the overwhelming majority of respondents reported that they found the contextualized learning opportunity more interesting and motivating than traditional approaches.

Judith Bennett et al. (2005) studied affective learning outcomes in the context of SAC. Survey data collected from experienced SAC teachers (n = 222) indicated that students in SAC demonstrated more positive responses to science lessons and activities, were more interested in science, and were more likely to pursue science studies at the university level than their peers in non-context-based courses. Barber (2001) also studied outcomes associated with SAC. Barber concluded that SAC students expressed higher levels of interest in and more positive appraisals of their learning experiences than the comparison students. In addition, Barber found that a greater proportion of SAC students went on to take chemistry-related courses at the university level.

Like SAC, Chemie im Kontext (ChiK) is a context-based chemistry curriculum. It has been developed and implemented over the last decade in Germany. Ilka Parchmann et al. (2006) reported research associated with continuing redesign and implementation of ChiK units over a 3-year period. They collected data from teachers (n = 37) and students (n = 216) involved with ChiK as well as comparison data from students (n = 183) taking more traditional courses. The teachers tended to see their use of ChiK units as highly innovative and as a significant departure from traditional approaches to science education. However, most students tended to see ChiK units as unique in terms of context but generally consistent with other science learning experiences. Despite these perceptions, ChiK students demonstrated statistically significantly higher motivations to learn chemistry than the comparison students.

In two studies of similar SSI interventions, researchers documented statistically significant differences in pre- and post-surveys of science attitudes (Lee and Erdogan 2007; Yager et al. 2006). Stuart Yager, Gilsum Lim, and Rober Yager also collected data related to student participation in a number of home and community-based science activities like talking about science at home, contacting scientists, and participating in public forums. The intervention students participated in these events at much higher frequencies than their peers who participated in traditional classes.

Argumentation

Given the status of SSI as ill-structured, open-ended problems, SSI are ideal contexts for scientific argumentation, and advocates for SSI education have frequently suggested that SSI-based instruction can support development of argumentation practices. Several studies cited in previous sections also explored student argumentation. Anat Zohar and Flora Nemet's (2002) study investigated the effects of an SSI-related unit with an explicit focus on argumentation. A pre/post argumentation assessment was administered and scored based on the number of justifications provided, argument structure, counterarguments, and rebuttals. Intervention students performed statistically significantly better on the posttest than the pretest. These changes were described as having a large effect size. In contrast, comparison students showed no gains. The researchers also examined argumentation with small groups serving as the unit of analysis and noted "dramatic changes in the quality of students' arguments" (p. 46).

Dawson and Venville (2010) studied an Australian high school teacher who had participated in professional development focused on SSI and argumentation. The teacher employed a range of strategies for promoting classroom argumentation including encouragement of discussion, modeling argument, valuing different positions, prompting for evidence to justify claims, and promoting counterarguments. The argumentation practices of students ($n = 46$) participating in an SSI (related to genetic technologies) and argumentation intervention were compared with students ($n = 46$) who received genetics instruction with no explicit attention on SSI or argumentation. The intervention students produced statistically significantly more complex arguments to justify their decisions than students who studied genetics only. Factors attributed to the improvement of argumentation were the ability of the teacher to facilitate whole class discussion, the use of writing frames, the context and relevance of the SSI, and the motivation and interest of the students.

Virginie Albe (2008) investigated argumentation with a class of 11th grade students in a French school involved in the study of health effects related to the use of cell phones. Albe conducted a micro-ethnography with a focus on the dialogical and rhetorical aspects of discourse. She analyzed student argumentation through analysis of audio recordings and transcripts. Results indicated that the SSI provided a compelling context for student engagement in "collaborative argumentation" (p. 86). Students challenged one another to explain their views and consider the perspectives of others. Albe also documented ways in which students' naïve epistemological representations limited argumentation and suggested that, "students' work on socio-scientific controversies should be accompanied by an examination of the way in which scientific knowledge is produced within a community and, in particular the role of controversy in the process" (p. 86).

In a pair of studies conducted in Israel, Revital Tal and colleagues explored argumentation as students progressed through SSI-based units. In the first study, researchers administered pre/post questionnaires and analyzed portfolios constructed by students to showcase their argumentation practices. The researchers used a rubric for assessing argumentation with the following criteria: generativity, elaboration, justifications, explanations, logical coherence, and synthesis. Students performed much better in the post-intervention assessment for all criteria on the rubric except synthesis. Synthesis, which involved synthesizing diverse perspectives into more complex, coherent ideas, represented one of the more cognitively challenging criteria, and students scored relatively low on this in both tests (Tal and Hochberg 2003). In the second study, researchers worked with six classes ($n = 128$) of 10th and 11th grade students. The SSI-related intervention dealt with using the sea as a resource for agriculture and the environmental problems of local coasts and waters. In comparing pre- and post-intervention performance of groups of students engaged in discussions regarding SSI, the researchers concluded that group argumentation improved. These claims were based on frequency comparisons of the number of justifications used, the extent of use of scientific knowledge, the number of aspects incorporated, and the synthesis of counterarguments and rebuttals. Statistically significant differences were found for each of these criteria except the synthesis of counterarguments and rebuttals (Tal and Kedmi 2006).

Marcus Grace (2009) also examined changes in student argumentation and reasoning in response to an SSI-related intervention. In this study, students ($n = 131$) were engaged in relatively short "group decision-making discussions guided by a structured framework" (p. 1). The discussions related to biological conservation issues. Data were collected through pre- and post-intervention questionnaires and audiotapes of the group discussions; 52 of the participants demonstrated the same level of argumentation in the pretest and posttest questionnaires, seven students unexpectedly dropped one argumentation level, but 67 individuals improved one or two levels. Grace concluded that the intervention, which prioritized student reflection on their own ideas, produced substantial differences in argumentation practices.

Erminia Pedretti (1999) conducted a case study with a mixed class of fifth and sixth grade students ($n = 27$) studying the mining of natural resources in Canada. In this experience students completed a number of classroom-based activities about the topic including role playing, independent research, and debate and took a field trip to a local museum. Data sources included field notes and interviews with students and educators involved with the project. Pedretti framed the study in terms of decision-making, but much of what she examined was consistent with some of the argumentation frameworks presented above. She concluded that through the experience, students demonstrated positive improvements in their ability to consider multiple perspectives and compromise. Students also became more likely to be aware of and thoughtfully consider ethical considerations associated with their decisions.

A final argumentation study explored student argumentation in the context of scientific issues and as well as SSI (Aufschnaiter et al. 2008). This study involved six teachers who had participated in professional development about scientific argumentation and who successfully implemented a series of nine argumentation lessons. Data were collected through video and audio records of small group conversations in the lessons. The authors concluded that students demonstrated higher levels of argument when arguing about SSI as compared to science contexts. The authors suggested that the more familiar contexts provided by SSI likely contributed to the documented differences.

Conclusions

Overall, the research reviewed as a part of this chapter provides compelling evidence supporting the efficacy of SSI as contexts for learning science. Science learning can be defined in many ways, but we chose to operationalize learning in terms of four outcome variables that we believe are critical aspects of science education and that have been positioned as likely outcomes of SSI education based on the theoretical commitments that have guided this movement. We examined eight studies that explored science content knowledge, and all of these reports documented gains associated with SSI-based instruction. Many of these studies used a pre/post design. The four studies that utilized comparison groups (i.e., students studying science without an SSI focus) offered conflicting results. Two of these studies found that intervention students out-performed comparison students (Venville and Dawson submitted; Zohar and Nemet 2002); one study found no significant differences (Yager et al. 2006); and the final study found that comparison students demonstrated greater content gains than the intervention students. Additional work using well-established assessment instruments and frameworks will be necessary to decipher these relationships.

The oft-presumed association between SSI and NOS has been discussed conceptually much more than it has been tested empirically. The two studies that explicitly examine this link through an intervention study provided limited supporting evidence. In the first study, an SSI instructional context did not seem to significantly enhance or detract from an explicit NOS approach (Khishfe and Lederman 2006). In the second report, an SSI intervention supported student understanding of NOS, but the developed ideas were not robust enough to serve as conceptual resources as students participated in an SSI debate (Walker and Zeidler 2007). The final study in this section documented student gains in reflective judgment associated with SSI education (Zeidler et al. 2009). If prolonged SSI-based instruction can promote epistemological development, then it is reasonable to hypothesize, that under appropriate conditions, that NOS constructs could also be supported. Research that investigates differential effects of various issues and instructional models will be needed to further explore these issues.

The studies that examined generation of student interest and motivation to learn science provided the most consistent evidence supporting the efficacy of SSI-based instruction. The seven studies reviewed in this section documented student interest in learning science in the context of SSI especially as compared to learning science with more traditional approaches. Interesting support for this claim was also provided through assessments of student participation in the community relative to SSI (Yager et al. 2006) and pursuit of science-related college majors (Barber 2001). This research provides strong evidence for a positive relationship between SSI-based instruction and generation of student interest. It would be interesting to explore how educators might leverage this relationship for supporting science education.

Argumentation has been frequently invoked as a framework for exploring development of advanced ways of thinking among learners in the context of

SSI-related interventions. The eight studies that addressed argumentation produced evidence of student gains in argumentation, but at least of these reports highlighted student struggles with advanced argumentation practices in the context of SSI (Albe 2008) that have been documented more generally in investigations of scientific argumentation. These results suggest that SSI-related interventions can serve as effective contexts for development of argumentation practices, but the extent to which these interventions will be successful is highly dependent on the nature and quality of supports provided to students.

In conclusion, this chapter provides compelling evidence to support the integration of SSI in school science education. The inclusion of SSI in science supports the development of key learning outcomes: science content knowledge, nature of science, interest and motivation, and argumentation. At the same time However, there remains an urgent need for targeted classroom-based research to identify the relative impact of factors affecting the quality of instruction and the achievement of desired outcomes using SSI.

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Chapter 54
Technology in Science Education: Context, Contestation, and Connection

Alister Jones

One of the difficulties in writing about technology in science education is the perceptions that people have of technology are frequently associated with computers or educational technology (Cajas 2001). In fact, many national curricula, undergraduate and graduate courses in science education have sections on technology. However, these are often about using computers or multimedia to teach science concepts or processes. This represents a limited view of technology. The use of computers, as one of many educational technologies, provides important tools for the enhancement of learning across all curriculum areas but should not be equated to technology education or limit technology in science education to just the use of computers in the teaching and learning of science. Technology has played a central role in human societies and Roger Bybee (2000) notes that in late 1999, the Newseum, a journalism museum in Virginia, conducted a survey of American historians and journalists to determine the top 100 news stories of the twentieth century. He notes that in the top 100 headlines in the twentieth century, an estimated 45% were directly related to technology. Yet, as Roger Bybee notes, for a society deeply dependent on technology, and particularly in this so-called knowledge age, we are largely ignorant about technological concepts and processes, and the factors that underpin technological development and innovation. Also the lack of general notions of technological literacy is compounded by the other misconception that technology is simply applied science. Hence, we need to establish a new understanding of technology and in this case its relationship to science education. Technology in science education and the interdependence of scientific and technological literacy are becoming more prominent in the science education literature. For example, there are special issues on technology education in the journals of *Research in Science Education* (2001) and *Journal of Research in Science Teaching* (2001).

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The inclusion of technology within science education has been a site of debate, classroom research, and curriculum innovation.

This chapter explores the science, technology and society (STS) movement and the various stages it has been through in the last 25 years. Science teachers' perceptions of technology are explored and the implications they might have on the teaching and learning of science. The introduction of technological applications in science and the outcomes of this approach are explored as is the introduction of technological problem solving in science classrooms. The role and place of technology in science curricula is discussed as well as the possible integration of science and technology in the curriculum and classroom.

Relationship Between Science and Technology

The relationship between science and technology is a complex one. An analysis of both the nature of science and the nature of technology shows that there is a complex relationship between the two. Consideration of the nature of technology indicates that technological knowledge and practices are socially constructed and context dependent and where human mental processes are situated within their historical, cultural and institutional setting (Wertsch 1991). Therefore, technology is an activity that involves not just the social context, but also the physical context, with thinking being associated with and structured by the objects and tools of action. Technology is based within a philosophical, historical, and theoretical context (Mitcham 1994). It is its characteristic as an activity, as well as a body of knowledge that is salient. Technological activity makes the idea of practice most central, and hence the importance of technological practice. Technological practice is primarily about doing technology, as well as studying it and creating technological knowledge. This does not deny that those who do technology create knowledge either through technological activity or in a theoretical fashion or that there is unique technological knowledge. The uniqueness of technological knowledge, processes, and skills has not always been recognized in general education, although literature in the area is increasing (Jones 1997). People use technology to expand their possibilities, to intervene in the world through the development of products, systems, and environments. To do this, intellectual and practical resources are applied. Technology includes control, food, communications, structural, bio-related, materials, and creative design processes. From a research and development perspective, Paul Gardner's (1994) review on science and technology had a significant influence. He argued that the relationship between science and technology could be seen in four ways:

1. Technology as applied science
2. Science and technology as independent communities
3. Technology as giving rise to scientific understanding
4. Science and technology as equal and interacting communities

Technology can be utilized in a variety of ways in science education but, in doing so, it is important to have a clear concept both of the nature of science and the nature of technology. Too often in the past a limited view of technology in science has limited both the learning of science and the learning about technology. When technology is viewed as applied science it is assumed that there is a linear relationship in which science generates technology, and when this view is held, the story of a technological development is projected through the science lens (Gardner 1995).

It is therefore important that some of this complexity is apparent in science education. Unfortunately in the past a simplistic relationship of technology as applied science has held sway. It is time for a reevaluation of this relationship (Cajas and Gallagher 2001). Discussions about this relationship often were fruitless because a too simplified image of that relationship was used. The technology as applied science paradigm is well known. Defenders of this paradigm had no difficulties in showing examples in which this idea applied well. There is scarcely any doubt that the transistor would not have been invented in the Bell Labs without the use of solid-state physics. However, at the same time others could come up with equally valid examples for rejecting the technology as applied science view. They could come up with the example of the hot air engine that was invented at a time when the engineer's knowledge of thermodynamics was not very adequate. So valid cases could be used both for defending and for rejecting the technology as applied science paradigm. As Marc de Vries (2001) notes, it is important to distinguish between different types of technology because for some technologies the technology as applied science paradigm does apply, for others it does not. In some cases science and technology can be inextricably linked. For example, the laws of physics can limit technological innovation, and scientific activity can be constrained by factors such as commercial advantage. However, even in these instances, the purpose of science and technology is different. For the scientist the purpose is developing a greater understanding of the natural or even the made world. The purpose of a technologist is to intervene in that world and to change it in some way. This means that technological solutions will often be specifically situated, whereas scientific solutions are usually thought to be more generalizable.

Marc de Vries (2001) notes that the history of industrial research laboratories can offer a good opportunity for studying the complex relationships between science and technology. A good insight of these relationships is relevant for shaping a sound concept of science and technology in both science education and technology education. In his article, three different interaction patterns are derived from the history of industrial research labs (in particular the Philips Natuurkundig Laboratorium), namely (1) science as an enabler for technology, (2) science as a forerunner of technology, and (3) science as a knowledge resource for technology.

Science, Technology, and Society

The 1980s saw an attempt to include the theme of science, technology, and society (STS) in the research and curriculum agenda. Peter Fensham (1987) identifies 11 dimensions or aspects of STS learning. These are: the relation between science and technology; technocratic/democratic decision-making; scientists and socio-scientific decisions; science/technology and social problems; influence of society on science/technology; social responsibility of scientists; motivation of scientists; scientists and their personal traits; women in science and technology; social nature of scientific knowledge; and characteristics of scientific knowledge (scientific methods, models, classification schemes, tentativeness). The STS movement began due to a combination of factors, including the 1960s' growing concern that science education had become divorced both from its social origins, and from the social implications of scientific endeavor. This was often expressed as the "social relevance of science" (Fensham 1987, p. 1). There was also a push for science education to become more technology related. Introducing STS maybe seen as being a way to add to conceptual development or as alongside conceptual development in science (Hughes 2000). Joan Solomon (1988, p. 379), in fact, states that "STS has emerged as a discipline with a discernable history and development." Although STS in some places has become a subject in its own right, in many countries, an STS focus has often been an add-on in the teaching of science. It is important to note at this point that while technology is conceptualized within STS it is in practice very much aligned to applied science. An STS approach has also expanded into thinking about socio-scientific issues in science education.

The introduction of biotechnology as an area of research and development, including curriculum development in science education has provided a means to develop a much more research-focused agenda around science, technology, and society. Advances in biotechnology have social, political, economic, and wider cultural implications and present society with ethical issues and dilemmas which require informed citizens capable of contributing to public debate. An improved understanding of socio-scientific issues among young people will help to ensure they have an informed, defensible view and that they understand, for example, the rationale for national initiatives to combat environmental issues involving genetically modified organisms (Dawson 2003). As part of the reason for including social and technological issues is also to introduce values and ethics into science, it seems clear that students need opportunities to develop, reflect on, and justify their bioethical values. Vaille Dawson (2003) identifies the multiple skills involved in students' ethical decision-making: ethical sensitivity (in identifying the dilemma), ethical reasoning (identifying and weighing up arguments for and against different decisions), and ethical justification (reaching and justifying a decision). While approaches derived from STS programs, for example, case studies, structured debates, oral presentations, and scenarios, can be adapted to promote student questioning and decision-making about societal issues, many of these do not delve deeply into the social and ethical aspects.

Perceptions of Technology by Science Teachers

Teachers' concepts and practices have shown strong links with the initiation and the socialization of teachers into subject subcultural settings (Goodson 1985). Therefore, teachers have a subjective view of the practice of teaching within their concept of a subject area (Goodson 1985). This view is often referred to as a subject subculture, and leads to a consensual view about the nature of the subject, the way it should be taught, the role of the teacher, and what might be expected of the student (Paechter 1991). As technology was being increasingly linked with science education and as an area of study in its own right, concern was raised as to what were teachers' and also students' perceptions of technology. In the study conducted by Alister Jones and Malcolm Carr (1992) on teachers' perceptions of technology and technology education they found that all the science teachers who were interviewed saw technology education in terms of applications of science. In terms of teaching, technology was perceived to be a vehicle for teaching science and often something extra to the conceptual development in science. Many of the teachers at the primary and intermediate school viewed technology in terms of computers. For these teachers technology meant using computers or other technology to solve problems. Teachers also mentioned problem solving in relation to finding out how things work. Technology is seen as a mechanism for solving a problem or as a vehicle for approaching a particular type of problem solving, that is, finding out how things work, particularly in science at the secondary school level.

Judy Moreland (1998) reported that although elementary teachers stated they needed to learn more about the teaching of technology, they felt they had enough skills and understanding to be teaching technology and could do it in the classroom. One teacher with a science strength set the students applied science tasks (design a hot balloon after studying flight). Technological principles were not involved. The criteria were in terms of why things happened and a narrow focus of outcomes. Anne Northover (1997) noted that all the high school science teachers she worked with viewed technology as being applied science and technology as skills and skill development. The teachers went for minimal change and added technology into existing programs rather than developing new ones or new learning outcomes. She found that these teachers generally expressed an interest in technology and commented on the motivational aspects of technological activities. The dominant science subculture in schools proved to be a powerful conservative influence. Teachers who showed changed views of technology and biotechnology in the teachers' development program, by the end of their teaching often had reverted to the perspective held initially. In fact, where teachers did make changes to their initial perceptions, the cognitive dissonance set up by the disparity between their views and their practice was often resolved by reverting to a previously held view.

The strategies developed by the teachers in their classrooms when implementing technological activities were often positioned within that particular teacher's teaching and subject subculture. For science teachers these subcultures are consistent and often strongly held. The subcultures had a direct influence on the way the teachers structured the lessons and developed classroom strategies. Teachers developed strategies to allow for learning outcomes that were often more closely related to their science subject subculture than to including technological outcomes. Teachers entering areas of uncertainty in their planned activities often reverted to their traditional teaching and subject subculture. Teachers' existing subcultures in terms of teaching and learning, subject area, and school, in association with their concepts of technology and science, influence the development of classroom environment and strategies, and consequent student activities.

Introducing Technological Applications in Science

The introduction of technological applications was seen as a means of increasing the relevance and authenticity of science. Research in science education that explored the use of technological applications for the teaching of science, suggests such contexts do have a positive effect on students' learning of scientific principles and concepts (e.g., Jones and Kirk 1990). This research is in keeping with international research findings on the importance of context in student learning (Hennessey 1993). Alister Jones and Chris Kirk (1990) found that in using such applications as earthquake monitoring systems and baby breathing monitors, students indicated that these technological applications helped them to remember scientific concepts involved. No change was recorded, however, if the applications were used as an add-on either at the beginning or end of a lesson. The students also commented that the use of such technological contexts also provided frameworks for the construction of further scientific concepts to those specifically targeted. Another important outcome from this research was the significant increase in the student's level of confidence, interest, and enjoyment in science generally. Care must be taken, however, that the technological context used is appropriate to the students' interests and the scientific content, and that it is presented as an integral part of the learning experience rather than an add-on for the sake of sparking interest. Susan Rodrigues and Beverley Bell (1995) explored the role and effect of context on female students' learning of oxidation and reduction. Using such technological applications as breathalyzers, and hair perming and coloring systems as contexts, they found that not only did students become more interested in the scientific concepts of oxidations and reduction, but also there was an increase in the number and quality of classroom interactions both with each other and the teacher. The students appeared to take ownership of their learning.

There is an increasing body of research that supports the use of technological applications in science education. It would appear that student learning in science could be enhanced by using technological applications in order to increase their understanding of scientific concepts and principles, as well as increasing their enjoyment of science generally.

Technological Problem Solving in Science Classrooms

There have been many attempts to introduce technological problem solving in science classrooms. However, classroom observations undertaken in science classrooms when technology problems have been introduced have shown that the science classroom culture and student expectations can influence the way in which students carried out their technological activities (Jones 1994). The students in the science classrooms enjoyed carrying out technological problem solving and their teachers reported considerable enthusiasm for these activities. However, subject subcultures were a major influence on students' expectations of classroom practice, with regard to both themselves and their teacher. For example, the solutions that the students sought were often in terms of traditional solutions utilized in their prior experiences of the science classroom. When questioned, these students often clearly stated that they could have done more toward solving their problems, but they consciously limited themselves to what they considered was appropriate within the science classroom. Mike Forret (1997) investigated the early learning of electronics. He used problem solving and contextual approaches to introduce electronics to students. He found that students had an interest in electronics, had enhanced practical competence in constructing circuits and enhanced problem solving. Ian Ginns et al. (2007) highlighted that science learning outcomes can be identified in some students' technological activities. These learning outcomes were related to work that the students had covered earlier in the year. However, it was noted that opportunities for extracting science principles from technological activities have not been maximized. Norton et al. (2007) indicated that introducing technology in science allowed students to think for themselves, apply logical thinking, be creative, and allow for student autonomy. The introduction of technological problem solving in science can allow for greater problem solving and strategic thinking but not necessarily enhance student understanding of technology.

When technological problem solving is introduced into science classrooms, students are interested, enjoy the experience, and in many cases learn some scientific concepts. There is very little evidence of transfer of scientific knowledge to technological solutions and little understanding of the processes involved. The technological process adopted by the students is somewhat fragmented and appropriate solutions are not forthcoming. The culture of learning in science classrooms does not appear to lend itself to helping students develop technological capability or technological literacy. The introduction of technological problem solving into science classrooms needs careful consideration if technological literacy is a desired learning outcome in science.

Technology in the Science Curriculum

The late 1980s and 1990s saw the greater inclusion of technology as an area of study in science curricula internationally, for example, in England (Hughes 2000), in the USA (Cajas 2001), and in New Zealand (Bell et al. 1995). Internationally there was also an emphasis on the inclusion of technology as a vehicle for the learning of science. However, generally science curricula portray a narrow view of technology. Such a narrow view of technology relies on a concept of technology as very much focused on applied science. As has been stated elsewhere (Bell et al. 1995), the treatment of technology as embedded in science is cause for concern as it means that other forms of knowledge, including technological knowledge, which are all essential for technology, are not apparent. It also excludes many technological innovations and developments that have no direct links to science as a discipline.

These science curricula often introduce technology for the purpose of clarifying and demonstrating the scientific principle. At higher levels of some curriculum, the focus shifted to that of investigating in a very general way the relationship between science and technology, for example, acknowledging and understanding how technological advances have aided or in fact enabled the development or major rethinking of scientific ideas. When there was a focus on learning how technological artifacts function, this was in terms of scientific principles only, ignoring technological and other knowledge bases crucial to the successful functioning of technological artifacts, systems, and environments. The principles behind technological innovation are perceived to be only those belonging to science. There is some opportunity within this aim to see how technological developments impact on scientific knowledge, and vice versa. This opportunity is constrained to those technologies fitting the applied science notions of technological developments. There is also opportunity for exploration of the effect of technological development on society. However, it is specifically stated that the means of such an evaluation should be through the application of scientific knowledge.

Biotechnology is a curriculum area that is often highlighted as an example of where science and technology come together as equal partners. In most international curricula biotechnology appears within senior science and biology and correspondingly its classroom implementation provides examples of technology as applied science. However, this narrow focus of biotechnology may limit the exploration of sociopolitical or ethical dimensions of biotechnology in classroom programs, and provides limited opportunities for students to develop rich scientific and technological literacies (France 2007). France found that the position of biotechnology in science curricula internationally tended to place it within an applied science framework (technology as applied science). An expression of such applied science examples are: microbiological processes being identified within human health and disease, examples to illustrate anaerobic respiration (bread and ginger beer making), and the application of microbial degradation in waste disposal and composting. What are missing from most of the curricula are opportunities for discussion of sociopolitical issues as well as values inherent in technological processes. The positioning of biotechnology in this way means that technology itself is underplayed, as is the chance for students to develop a greater understanding of the relationship between science and technology and the values inherent in this. Biotechnology in terms of GM debates can put its inclusion in the curriculum more toward the discussion of controversial issues rather than consideration of a broader understanding of biotechnology in its wider context. However, the aligning of biotechnology only with controversial issues also means that students may develop a distorted view of biotechnology rather than seeing it in its fuller context. This representation of technology in science only shows a relationship in terms of science to technology as application and this represents a view of technology as being applied science. It also tends to reflect a deterministic view of technology and in fact science for that matter.

Integration of Science and Technology

The integration of science and technology is seen as a means of combining these areas. However, this can be problematic as highlighted in the previous sections. Grady Venville et al. (2002) explored in detail notions of curriculum integration and what it might mean from both a theoretical and practical perspective. They explored the nature of integration and how it is represented in the school environment. They also examined why integration should be considered and focused on student engagement and whether integration enhances learning in science. These authors highlight several studies that show an authentic curriculum related to student needs and interests and to the world outside of school, results in increased participation and engagement, and reduces alienation. In their paper they highlight how competitions such as the Science Talent Search provide opportunities for the integration between science, mathematics, and technology. They indicated that subjects such as science, when placed within an integrated curriculum that is based on content, is difficult to assess and relatively open to debate. They provide an example of integrated practice involving the use of technology-based projects. High School students worked on a technology project for 10–12 weeks that included technology, science, and mathematics research components. An example of a technology project brief was to design and produce an electric powered vehicle that could climb a steeper gradient on the standard test track than any others. The technology aspect investigated traction options, materials and construction techniques, motor mounting options, and power transmission systems. The science aspect investigated friction, gears and pulleys, torque and power transfer, and how scientific trials influenced their choice of traction, gearing, and drive options.

This is an area for further research but cognizance needs to be taken of the way in which science as a high-status subject and teachers' and students' perceptions of and understanding of the relationship between science and technology will influence the outcomes in the classroom. In integration of science and technology then, technology is often seen as the context to teach science and problem solving rather than teaching about both science and technology.

Conclusion

This chapter has considered ways in which technology has been included in science education research and development. A broad notion of technology was taken in terms of people using technology to expand their possibilities and to intervene in the world through the development of products, systems, and environments. To do this, intellectual and practical resources are applied. Technology includes control, food, communications, structural, bio-related, materials, and creative design processes. It is important that teachers and students develop an understanding of technology and science as two areas that can interact but are also distinct in nature. Technology is a discipline in its own right (Mitcham 1994) and is not a subset of other learning areas. For example, technological knowledge is not reducible to science, mathematics, or social science. Science must not be seen as a gatekeeper for students undertaking further work in technology, as this will limit students' learning in both fields.

The rationale for the introduction of technology in science has centered on an attempt to increase the relevance and authenticity of science to students. There is evidence that when this is introduced in an appropriate way, there is increased enjoyment and even improvement for some students in science achievement. Technology was essentially perceived as applied science and this influenced the way it was introduced to the classroom. The introduction of technology and also social aspects allowed for values and ethics to be introduced into the science classroom, particularly in relation to biotechnology in biology classes. The introduction of technology into science classes has seen technology dominated by the science subculture. When technological applications were introduced in a themed approach rather than as an add-on, students were more likely to be engaged in science, enjoy it more, and achieve both in science and technology. In the science curriculum, technology has been essentially introduced as applied science although at the higher levels of the curriculum, technology is seen as advancing science. However, the focus was on the direct links with science rather than social or technological principles. The introduction of STS and technological applications can enhance the learning of science concepts and increase students' interests and motivations. However, if technology is taught as a subset or as subservient to science, then this will be detrimental for student learning of a clear understanding of technology.

The potential of technology to make a difference in the teaching and learning of science has probably not reached the potential we thought it might when we began exploring its introduction 25 years ago. Technology in science education is used as a context and also provides connections for students. However, its place is still contested.

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Chapter 55
Web 2.0 Technologies, New Media Literacies, and Science Education: Exploring the Potential to Transform

April Luehmann and Jeremiah Frink

Introduction

The title of our chapter is bold – potential to transform? You may be doubtful, and rightly so, as many sophisticated technologies have preceded those known as Web 2.0 and, with few exceptions, their impact on science education has largely fallen short of expectations. The following vignettes show why we think this time it may be different.

Vignette 1

Mr K, an 11th grade pre-calculus teacher, feels his students need more time with the concepts they are working on in class, and decides to capitalize on students' interests with the Internet by integrating blogging into daily classroom practice. Each day, one student is expected to scribe the day's lesson in his or her own words and, thus, collectively, the class would be, as the teacher encourages, constructing a textbook for the world. Though no specific guidance was given, students quickly took up the practice with fervor – posting warnings, reminders, elaborate graphs and diagrams, inside jokes as well as apologies for imperfections – all addressed to their peers. Though most students shared an initial skepticism about blogging, they unanimously described their ultimate dependence on the blog for understanding the course content and participating successfully in class. They also described its contributions to development of community and shared ownership in each other's learning. Though the

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teacher did not introduce it with such lofty goals, the lived classroom blog transformed how students engaged with the concepts and participated in their own meaning-making around mathematics. (See http://pc30s.blogspot.com for one of this teacher's classroom blogs and http://oletango.blogspot.com/2006/01/what-if-your-blog-was-gone.html for his students' perceptions of their blogging experiences).

Vignette 2

Ms Frizzle (as she refers to herself), is a progressive and passionate middle school science teacher. At the time of her blogging, she was working in an alternative school in the Bronx where she is the only science teacher – and therefore the only teacher in her school trying to implement student-centered, inquiry-based science instruction as a means to empower her urban students. Only 3 years out of graduate school, she has passionate commitments and creative ideas, but also many questions about how to engage her students centrally in their own science learning in ways that transform their school science identities. She turns to blogging as her primary means to think on paper and engage with a like-minded professional community. She posts regularly (3–4 times a week) with stories of her daily adventures filled with wonderings, commentaries on resources she found useful, rants consisting of passionate and well-supported arguments about pedagogical dilemmas and social justice issues, and requests for support and help. A blogging community soon develops that provides Ms Frizzle with encouragement, resources, and collaboration, thus transforming her professional learning. (For a sample of Ms Frizzle's blogging work, see http://msfrizzle.blogspot.com/.)

Both of these real-life examples suggest that blogging, as well as other technologies such as wikis, video/photo sharing, social bookmarking, and multiuser virtual environments (often referred to as Web 2.0 technologies) can indeed play a key role in implementing the vision for science education agreed upon by many professional organizations, but rarely a reality in schools. For years, national reform movements in science education have been advocating for student-centered instructional design that results in students conducting investigations over time, providing evidence-based argumentation and explanations, developing understandings, abilities, and values of inquiry as well as of science content, working collaboratively to analyze and synthesize data, and publicly defending ideas and work (e.g., National Research Council (NRC) 1996). This, in turn, calls for learning experiences that elicit and explicitly build on learners' individual prior understandings, skills, and creative expressions; experiences that capitalize on social networks to support interpretation and meaning-making; and experiences that engage learners centrally in the authentic and core practices of a given discourse – exactly what we saw happening in Mr K's class and Ms Frizzle's blog through the practice of blogging.

While these considerations suggest the potential of Web 2.0 technologies for the future of science education, we have found very little research on this topic in the science education literature – especially of an empirical nature. Therefore, our goal in this chapter is twofold: (a) to report on selected results of research on Web 2.0

technologies outside of science education informed by New Media Literacy (NML) as a theoretical paradigm, and (b) to report on our own empirical research to date on the use of just one Web 2.0 technology – blogging – with science teachers and students, as an example of the kind of empirical research on these emerging technologies that could be especially fruitful for science education. First, though, some information about Web 2.0 technologies and NML is needed.

Web 2.0 Technologies, New Media Literacies, and Their Potential Relevance to School Science Reform

What do we mean by Web 2.0 technologies. These are new technological tools – such as those listed in Table 55.1 (although new ones continue to be developed every day) – that allow for easy viewing and creation of content along with the capability for sharing, editing, commenting, connecting, or tagging, all means which allow others to interact with the content created. The following characteristics set them apart from their predecessors: (1) access – to both ever-expanding information resources and to a variety of people, cultures, and potential identities (e.g., Gee 2003); (2) connectivity – with the interlinked network of other people, information, and ideas through the webbed structure of these social tools (e.g., Livingstone 2003); and (3) multiple modalities – for expanding the mediating practices which construct relationships and knowledge (e.g., Jewitt 2008).

NML, in turn, is a theoretical framework that has been used to explore the uncommon participation opportunities made available through these emerging technologies. NML redefines literacy as not just reading and writing but rather the process

Table 55.1 Examples of Web 2.0 technologies and related practices

Web 2.0 Technology	Related practices
Publishing and commenting (a) Blogging (b) Pod/vodcasting (c) Micro-blogging (d) Streaming Media (e) Audio/video commenting	User-centric organizing of content and tools (a) Employing Really Simple Syndication (RSS) (b) Building mashup applications (c) Creating compound documents
Socially constructing and categorizing content (a) Co-constructing wikis (b) Sharing documents (c) Video/photo sharing (d) Creating media mashups	Communicating in real-time (a) Text-based instant messaging (b) Audio/video instant-messaging (c) Document and application sharing
Connecting to people and information (a) Social networking (b) Social bookmarking/folksonomy/tagging	Interacting in complex interactive environments (a) Gaming (b) Participating in simulations (c) Engaging in multiuser virtual environments

Table 55.2 Linking science education goals with NML affordances

Reform-based science goals	NML affordances
Engaging students in: • Collaborative investigations over time • Productive public communication of ideas and work	Prioritizes: • Participation in developing global community • Collaboration • Distributed knowledge
Enabling students to: • Provide evidence-based argumentation and explanations. • Analyze and synthesize data and defending conclusions	NML are: • Openly authored, placing the requirement for evidence on the author • Situated practices in both the type of technology and the way it is used • Transactional processes that invite experimentation and pushing boundaries • Multiple, multimodal, and multifaceted
Students develop: • Understandings, abilities, and values of inquiry. • Knowledge of science content	Requires: • New social practices, skills, strategies, and dispositions for their effective use

and practices of meaning-making within social networks. Key to NML is a focus on collaboration, distributed expertise and authority, and collective or shared knowledge (Lankshear and Knobel 2006). Unlike frameworks such as instructional technology, information technology, educational technology, and computer aided learning, which foreground the computing devices used in the classroom setting, NML shifts the focus to the impact these emerging technologies have on socially constructed meaning-making. As Bill Cope et al. (2005) warn us, it is not the tool itself that affords these new forms of participation, but rather how the tool is employed by specific users in a specific context. This is well illustrated in our two vignettes, as in both cases the realized benefits of blogging depended on the specific ways the teacher decided to use this tool and create learning opportunities around it, as well as the various ways other participants (students or colleagues) chose to take up or engage with and even change these activity structures (e.g., DeGennaro and Brown 2009).

There are interesting parallels between NML and a reform-based vision of science education – as both represent a paradigm shift from traditional, transmission model of learning that most of us have experienced as learners (e.g., Anderson 2002) and are still prevalent in schools. To make this more evident, in Table 55.2 we have identified essential goals of reform-based science and matched these with critical elements of NML (based on the extensive literature review by Julie Coiro et al. 2008).

The parallels highlighted in Table 55.2 suggest that carefully designed classroom engagement with Web 2.0 technologies could provide science teachers and learners participation structures not common (and some not possible) within traditional classroom learning (e.g., 50-min, synchronous class periods, geographically constrained by four-walls within a given building), which, in turn, could help meet science goals. Yet not all classroom applications of these technologies will realize this potential due to a shift in mindset required by NML which is the critical catalyst connecting the learning opportunities and the specific uses of a tool. (More about this necessary shift in mindset is offered later in this chapter.)

Selected Findings from Research on Web 2.0 Technologies and NML Outside of Science Education

As Web 2.0 technologies are only now emerging and empirical research on their use in science education is very limited, it is worthwhile for science educators to learn from research conducted in other educational settings using the framework of NML. A recent search of the top 15 journals that relate to education and educational technology (as rated by the impact factor in the Journal Citation Reports database) identified only 89 articles on the use of Web 2.0 technologies in school settings, most of which lacked empirical consideration of either implementation or impact. These findings are similar to those of Ian Robertson (2008), who conducted a much larger search focusing on just wiki and blog technologies. Yet selected examples from this body of research can be helpful in explicating the issues and concepts that are emerging within this arena – as summarized below.

Methodological Considerations

An important lesson gained from these pioneering research studies is that unique methodological issues emerge when researching Web 2.0 technologies. Particularly informative is Margaret Cox's (2008) historical analysis of the evolution of research questions and agendas in education from the 1950s to the present as technology changed. First, her study highlights the importance of addressing issues specific to changes in technology. In response, we propose the following:

- Can we transfer the tools of research to the online world (Jones 2004)?
- How do we keep a clear research focus when crossing disciplines (Livingstone et al. 2008)?
- How do the technologies and practices intersect and inform one another (Anderson 2008)?
- How do we develop methodologies when participants (Leander and McKim 2003) and artifacts (Burn 2008) are socially constructed, spatially distributed, and constantly changing?

Second, she points out that particular types of questions call for particular methods and approaches. Below we identify primary types of research questions that are especially relevant to applications of Web 2.0 technologies in education and how some researchers have addressed these questions productively:

- *How are these technologies being used in educational settings?* These studies are typically large-scale investigations aimed at understanding the way that Internet technologies are used, accessed, and implemented (Anderson 2008). While each study utilized different tools, overall most employed surveys of large groups to describe trends in the use of tools.
- *What interactions are occurring due to the integration of these technologies in education?* As this area of study is so new, many questions currently posed around NML relate to understanding the learning environment and the interactions occurring in that environment. These questions suggest methodologies and approaches that are more ethnographic in nature. Field observations involve participating in the environment, whether as a lurker reading the posts being created or as a more visible participant who has created an avatar in a 3D virtual environment.
- *What is the impact of use on the classroom, teacher, and students?* Here the focus is on understanding the experiences of the individual within the online environment and how these experiences change the actions, practices, and meaning-making process of that individual – whether teacher or student. Case studies have been used to study the experiences of youth in digital environments (Thomas 2008), relating to identity (Gee 2004), agency and authority (Hammer 2007) or literacy development (Lam 2006), as well as the experiences of teachers as they implement Web 2.0 technologies in their classroom (Leander 2007) or use them to develop their own identities as reform-minded science teachers (Luehmann 2008a).

Relevant Findings

Five themes emerged from a consideration of the current literature on the use of Web 2.0 technologies in education. Below we examine each of these themes, highlighting the work that has been done in NML within education more broadly; these same themes are used later to discuss findings of our NML work in the contex of science education.

Potential for Teaching and Learning

This theme, threaded throughout the literature on these technologies, often explores out-of-school practices to see what learners do with these technologies when not under the constraints of teacher and curriculum goals (e.g., Gee 2004). James Gee's (2003, 2004) foundational work on the learning principles informing participation in video gaming, as well as his discussion of online spaces when looking at gaming communities, highlight the powerful affordances that these technologies hold for learning. While drawing implications for how educational communities could utilize these technologies, he also recognizes that the affordances he identifies may not translate to classroom learning because of differences in participants' motivation and purposes for engagement.

Identity Work Facilitated by These Technologies

The reflective, social, and flexible nature of Web 2.0 technologies make them ideal to support (and study) changing identities (e.g., Carlone and Johnson 2007). Rebecca Ward Black (2007) followed the use of fan fiction writing for a student in an English as a Second Language (ESL) classroom. Black noted the ways in which, through authentic, written interaction, the student refined her use of language while working to develop her identity as a competent user of English.

Construction and Social Organization of Content

The social and shared nature of Web 2.0 technologies opens up new ways to construct and organize content both within and outside the classroom (Davies 2006). In his research on the use of wikis by preservice teachers during field placements, Ian Robertson (2008) found that using this Web 2.0 technology resulted in students and their teachers assuming additional roles as well as investing more in the organization and relationship of content.

Necessary Change in Mind-Set

To benefit from the learning affordances identified above, participants must shift the way they consider possibilities, goals and ways to achieve these goals (Lankshear and Knobel 2006), as using new media literacies represents a dramatic shift in how we interact with one another and what we value. Greater value needs to be given to actions and knowledge that are dispersed over those individually held, tools used for mediation and relationship-building over those used for knowledge production, a focus on the collective rather than the individual, and a move to digital multimedia spaces from stable, textual spaces. Kevin Leander (2007) examined the use of online technologies in classrooms where every student had a laptop. He identified the critical impact of teachers' attitudes and beliefs regarding how knowledge is constructed on the roles offered and taken up by students and teachers.

Lived Practices and Uptake

Web 2.0 technologies involve movement toward more equalized power structures due to the ability for multiple users to be instrumental to the development of the sites.

As these practices are brought into the classroom setting, the ways students take up (or don't) the teacher's instructional design become critical to its successful implementation as shown in a study by Leonard Annetta et al. (2008) of the use of virtual environments in a graduate class. They found that the variations in the ways that students negotiated and lived out the student-teacher's assignments had a significant impact on the extent to which the teachers' designed affordances were realized.

Empirical Research on Science Teachers' and Students' Bloggings as a Case

The use of Web 2.0 technologies in science builds on work which has been discussed within this handbook and other published work (e.g., Webb 2006). While recognizing the potential of technology for enhancing science education in her study of varied instructional technologies (IT), Mary Webb suggests that for true integration to happen, a redesign of the science curriculum is necessary. Although her focus was primarily on less connective forms of technology than Web 2.0, her arguments hold for these new technologies as well.

To offer deeper insights about the implications of NML for science education, we now briefly report on four complementary empirical studies informed by NML where we investigated ways in which science students' and/or teachers' blogging practices nurtured reform-based learning:

- Classroom Blogging 1 (CB1): This study examined how two teachers – Mr K, the veteran math teacher featured in the first vignette, and Ms T, a first-year biology teachers – introduced, structured, and used very different classroom blogs for their classes, and the learning opportunities and benefits students and teachers derived from these experiences with blogging (Luehmann and MacBride 2008; MacBride and Luehmann 2008).
- Classroom Blogging 2 (CB2): This study expanded on the previous one by investigating various components of teacher instructional design and corresponding lived experiences of nine additional science classroom blogs to which middle and high school students actively contributed (Luehmann and Frink 2009).
- Teacher Blogging 1 (TB1): The blog created by Ms Frizzle, the extraordinary science teacher blogger featured in our second vignette, provided very rich material for an in-depth case study of how this teacher used blogging very effectively as a professional development and advocacy tool (Luehman 2008a, b).
- Teacher Blogging 2 (TB2): In this study, we investigated how maintaining personal professional blogs in a graduate course supported 15 practicing science teacher learners (Luehmann and Tinelli 2008).

Table 55.3 briefly identifies key elements of each of these studies.

Table 55.3 Overview of four studies of blogging in science education

Study	Bloggers	Research questions	Data sources	Key findings
CB1	Class – 11th grade pre-calculus; 9th grade biology	How did each teacher structure, and students use, the blog? What were the participants' perceived benefits?	Teachers' interview; blog content (1 year each); students' written descriptions of blogging impact	Identified different blogging practices. Defined learning opportunities afforded by different blogging activity structures as well as key components of these activities. Described perceived benefits of teachers and students.
CB2	Class – nine diverse science classrooms	What affordances do blogs offer science teachers engaged in implementing reform? How were teacher designs taken up by students?	Teacher responses to five reflective prompts, blog content (3 months each).	Described range and representativeness of classroom blog uses. Investigated alignment of priorities across three phases of teacher design. Identified opportunities for and impact of teacher-designed student agency. Investigated range of ways various instructional classroom designs were lived.
TB1	One exceptional science teacher blogger	How and why did blogging provide opportunities to engage in teacher learning and identity work?	Blog posts and comments (1 year), email exchanges, phone interviews with colleagues	Described the personal professional use of one exceptional teacher blogger with special attention to how blogging supported wrestling with challenges of being an urban reform-minded science teacher. Identified perceived professional learning benefits. Explored connection between realized benefits and investment in blogging practices.
TB2	Fifteen secondary science teachers in a graduate-level course	In what ways did blogging provide opportunities for social interaction that supported professional learning among practicing science teachers?	Blog contents (1 year); blogging survey responses.	Described perceived benefits of personal professional blogging for science teachers. Explored various types of cognitive, emotional, and social work participants collaboratively engaged in through blogging.

Methodological Contributions

Throughout these four studies, as we tried to explore the realized potential of blogging to transform science education toward more reform-based practices, we have wrestled with a number of methodological issues similar to those reported earlier from the literature:

- How does one search for powerful examples of classroom blogging, as many are not public and few evidence the shift in mind-set allowing for a dominant student presence? We used websites targeting their blogging tools for K–12 education (e.g., EduBlogs). We also employed a snowball method (Goodman, 1961) to identify strong examples – namely, once we found one blog evidencing an NML mind-set, we used its blogroll and "shout outs" to identify others.
- How can a researcher interview teacher bloggers in ways that supports connection-making with the blogging practice? We have used Skype and Voicethread, two additional Web 2.0 technologies, as tools to conduct our bloggers' interviews, as they allowed interviewees to employ multimodal and hyperlinked resources to enhance their responses.
- How can a researcher characterize general use of blogging? To paint the landscape of particular learners' use of blogs as a basis for exploring participation structures and benefits, we repeatedly employed a number of descriptive statistics such as: (1) number of posts, comments, lines, and questions written by students compared to teachers; (2) number and types of multimedia elements employed; and (3), number of explicit connections to others through hyperlinks, references, or dialogues. In addition, we regularly counted instances of emergent themes for focus of post (e.g., a day-in-the-life, social justice, inquiry) and type of work (e.g., wrestling, ranting, resource-sharing).
- How can researchers study an environment that has the potential to constantly change? Blogs, like all Web 2.0 technologies, can constantly evolve. In order to freeze participation to allow us to analyze its use, blogs were transcribed through a process of copying and pasting their contents, including a screen shot of the home page, into a word processing document with line numbers added.
- How can researchers most effectively tell the stories of the implementation and impact of the integration of NML in science education contexts? Online peer-reviewed journals offer a valuable alternative to print-based media to report on Web 2.0 technology research. For example, our article on classroom blogging (Luehmann and MacBride 2008) published in the online journal *THEN* (http://thenjournal.org/feature/175/) allowed us to embed primary and secondary sources including hyperlinks to specific student and teacher posts and a podcast of the interview with the teacher blogger.

Key Findings

Using the same organizing themes identified earlier, we now highlight key findings that span our published work. These findings can be used to situate or inform other investigations of blogging or to inspire similar work with other Web 2.0 technologies.

Potential for Teaching and Learning

Clearly, our primary goal for studying blogging in science education has been to explore its potential for supporting teaching and learning. Our findings from the analysis of Mr K's and Ms T's classroom blogs (CB1) revealed that students as well as teachers felt that blogging nurtured classroom community, encouraged voices not often heard in classrooms (e.g., non-English speakers, multimodal, typical non-speakers), provided students more and different valued opportunities to understand course material, nurtured a sense of ownership of learning, provided uncommon opportunities to learn participation skills unique to online environments, and provided the teacher with a unique window into student thinking.

Our work to understand how participation in blogging might support science teacher learning demonstrated that blogging contributed to Ms Frizzle's development of her professional vision and dispositions; led to new understandings of content, pedagogy, and her students; and positively affected her practice by helping her in planning – all dimensions of teacher learning identified as important in the literature. In addition, she engaged in many practices deemed valuable in the teacher education literature: connecting practice to her autobiography, engaging in critical inquiry, interacting with professional community, critically reflecting on practice; integrating expert voices, and engaging in long-term professional work. (TB1). These same practices were also used productively by science teachers' blogging in the context of a graduate class (TB2).

Clearly, however, this learning and impact depended on the unique ways in which blogging was implemented and taken-up in each case – as addressed later.

Identity Work Done Through These Technologies

We employed the theoretical lens of identity development for much of our research conducted on teacher learning through blogging, because we feel it offers a long-term and holistic look at the person doing the growing and respects that learning involves much more than simply cognitive growth and development (Luehmann 2007). Our findings indicate that in addition to the cognitive work of wrestling with dilemmas, blogging gave teachers uncommon opportunities to engage in the emotional work involved in implementing reform as well as the social work that can support both of these other types of work (TB2). Blogging also provided opportunities for telling powerful stories of oneself and one's practice, fostering a unique professional community, demonstrating confidence in a variety of professional roles, positioning oneself in larger professional discourses – all important elements of identity work (TB1, TB2).

Construction and Social Organization of Content

Through our work, we learned that classroom blogs are more different than they are similar due to teachers' activity designs. When examining the nine classroom blogs (CB2), we were able to identify 11 unique activity structures (i.e., assignments or specific uses) used in science classroom blogs, only four of which were engaged by half or more of participating teachers. We learned that teacher instructional design of classroom blogging consisted of four distinct (and rarely aligned) components: curricular goals, instructional priorities, activity structures, and contents of rollout to students. Finally, not surprisingly, the degree to which the activity structure, as it was introduced to the students, allowed for students to exercise agency determined to what extent students *could* interact with teachers to modify how the classroom blogging was being used and in so doing maximize and individualize realized learning benefits.

Realized professional learning benefits of teacher blogging were connected to two primary and complementary conditions: the presence of an active blogging community and the investment of the blogger. An active blogging community was nurtured through publishing detailed posts, soliciting input, referencing others work, and offering detailed descriptions of issues. Clearly, the teacher blogger must commit a significant amount of time and effort to this professional practice to fully reap its benefits. These elements (community and investment) represent a reciprocal relationship, as we found that the primary motivation for engaging in blogging is the social networking made possible through the blogging community (TB1, TB2).

Necessary Change in Mind-Set

Realized benefits of classroom blogging were the result of the nuanced ways activity structures were implemented by a given teacher (e.g., required elements, option of anonymity). Activity structures in the classroom blogs we examined (CB1, CB2) varied dramatically with respect to their alignment with the priorities of either reform-based science education or those of NML. Evidence of the teacher mind-set could be found in a number of key decisions with respect to instructional design: the level of involvement of outsiders; the positioning of students (as authors of posts or just comments); the presence of positive interdependence of students with one another; the length of the blogging experience and the degree of student autonomy.

Lived Practices and Uptake

The realization of certain blogging affordances in classroom practice was not simply a matter of correct design, however; lived experiences, determined by both how students took up the design (or not) and how the teacher responded to students' participation, contributed to the resulting benefits of classroom blogging (CB1, CB2). There were times students did more than what was asked of them in the teacher-designed activity structure; in these instances, blogging enabled students' access to additional resources and opportunities for learning such as hyperlinked and multi-modal resources, a broader community and audience, and additional and different opportunities to engage peers and the teacher. This finding suggests that blogging, by itself, holds potential for scientific work to emerge through students' (as well as teachers') initiatives (CB2).

Conclusion

This chapter started with a bold statement regarding the convergence of reform-based science education and the learning affordances of emerging technologies. Both our research and others cited in this chapter provide evidence that Web 2.0 technology is already enabling the change that many in science education have sought for years. The emergent nature of this dialogue requires that we make recommendations rather than conclusions. Critical to framing our movement forward are the following suggestions:

- Research needs to continue to focus on the intersection of the goals of reform-based science goals and the meaning-making practices enabled by newer technologies.
- Investigating NML requires reexamining typical research methods and designs to employ those that consider unique implications of Web 2.0 technologies in the context of reform-based science education.
- Many additional Web 2.0 affordances specific to science education will need to be identified and examined through cases of actual implementation.
- Although we have identified five specific themes in the literature, many potential research areas remain such as scaffolding online participation over time, exploring interactions between in-class and online practices, and designing for positive interdependence with peers as well as outsiders.

Due to the critical convergence of the goals of science education and the affordances of emerging technologies as identified in this chapter, it is indeed time to further explore this potential to change the ways that learners are engaged in their learning, both students as well as teachers.

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Chapter 56
Leading the Transformation of Learning and Praxis in Science Classrooms

Stephen M. Ritchie

Transformative Capacity of School Leaders

In her recent keynote address to Australian teachers, Judith Sachs (2007) argued that teacher leaders have the capacity to transform schools and influence the learning outcomes of students and the practice of their teaching colleagues. The emphasis on transformation is not surprising here, given that the leadership literature has privileged transformational leadership in schools. The study of implementing technology curricula in primary schools in Australia, for example, led Léonie Rennie (2001) to conclude that 'effective leadership and collaborative support promote change' (p. 64). Transformational leadership is congruent with cultural change with the focus being on 'the people involved, their relationships' and the transformation of 'feelings, attitudes and beliefs' (Hopkins 2003, p. 56). This implies that transformative teacher leaders empower staff, foster collegiality and shape shared vision (Busher and Harris 1999). These views are embedded in Jennifer York-Barr and Karen Duke's (2004) definition of teacher leadership as 'the process by which teachers, individually or collectively, influence their colleagues, principals, and other members of school communities to improve teaching and learning practices with the aim of increased student learning and achievement' (pp. 287–288). At the time of their review, Jennifer York-Barr and Karen Duke (2004) noted that teacher leadership was under-theorised and that few empirical studies had been conducted. Since then, there is some evidence from the literature of a movement beyond descriptive research to greater attention to the advancement of theoretical notions of teacher leadership and leadership more generally. The purpose of this review is to identify these

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developments in the context of science education and forecast implications for practice, further research and theoretical development.

Just as designated leaders such as principals and department coordinators have responsibility for discharging particular leadership roles, leadership practices can be observed across a school (e.g. Ritchie et al. 2007). Science teacher leadership also could be realised within supportive professional networks beyond the boundaries of a school fence. These networks can be organised either as part of formal institutional arrangements or as informal non-institutional initiatives.

The Project for Enhancing Effective Learning (PEEL 2007) is an example of sustained leadership of teachers transforming practice within and across schools. PEEL was initially a 2-year project in Australia in 1985 that allowed ‘teachers to act to change their educational ideas and practices. Change occurs through collaborative reflection on practice’ (Baird 1992, p. 8). According to John Baird and Jeff Northfield (1992), ‘real change only occurs when teachers change’ and pressure for changing teaching praxis came from the PEEL teachers’ ‘personal dissatisfaction with what they were achieving with their students and the support for their efforts from colleagues expressing similar concerns and being willing to share ideas and experiences’ (p. 293). For over two decades, PEEL has generated strategies and articulated principles for effective teaching for high-quality learning. PEEL’s principles emphasise purposeful teaching procedures, sharing responsibilities for learning with the students and generating new pedagogical knowledge, while being supportive and collaborative with colleagues (Mitchell 2007). It has instilled a sense of community within the teaching profession both nationally and internationally. As a consequence of Galen Erickson’s visit to Monash University, the first PEEL group was formed in a Canadian school in 1992, thus dispersing local initiatives from Australia to an international forum (see Erickson 2000). Other PEEL groups have formed in Denmark, Sweden and Malaysia. PEEL’s effectiveness for influencing teaching practices is evident through the many contributions to PEEL SEEDS – a forum for PEEL teachers – that provide testimonials on how teaching practices have changed as a result of teachers’ participation in PEEL practices and fora.

While there are numerous other examples of teacher leaders transforming pedagogy and curricula internationally (Elliott 1991; Spiegel et al. 1995), too many to review in this chapter, very few studies deal with teacher leadership specifically. More commonly, reports (e.g. Tytler et al. 2008) recognise the importance of teacher leadership without defining what the authors mean by the term and the theoretical perspective(s) that shape their perceptions of leadership practice (e.g. Sachs 2007). To make an impact on the wider educational community, science education researchers will need to embrace the most recent theoretical work on teacher leadership.

As evident from PEEL, classroom teachers have the capacity to influence and transform cultural practices within schools. Students also have the capacity to influence what happens in their classrooms and schools, particularly in schools where organisational structures afford opportunities for shared, collective or distributed leadership (Lingard et al. 2003). Distributed (collective) leadership is a theoretical perspective that has received much attention in the recent leadership literature. I now consider the shifting emphases from individual to collective leadership discourses.

From Individual to Collective Leadership

Rather than reviewing the numerous studies of science teachers transforming their practice for their students, I restrict my attention to those studies that refer specifically to teacher leadership in one form or another.

Individual Perspectives of Leadership

When research questions focus on particular 'subjects' like department coordinators, principals and teacher leaders, the theoretical stance and research outcomes probably will be individualistic rather than collective. For example, in my first study of leadership practices (Ritchie and Rigano 2003), the focus was on what a particular department coordinator (i.e. Mr Cresswell) believed and how these beliefs were enacted in his praxis. The theoretical standpoint was *collaborative individualism* that positions a teacher leader as one who tends 'to be individualistic, collaborating with others intuitively and emphatically through shared vision of the possible' (Limerick and Cunnington 1993, p. 142), a stance somewhat consistent with Judith Sachs's (2007) thesis. Mr Cresswell demonstrated a personal commitment to professional learning and a caring ethic that he fostered towards learners, and he had contributed to the development within the department of a collaborative culture with other teachers who shared a vision for successful learning outcomes for their students.

Several international studies of individual teacher leaders have featured in the science education literature. In the USA, for example, Ann Howe and Harriett Stubbs (2003) reported three case studies of teachers who became teacher leaders through a professional development programme that emphasised mutual respect, challenging tasks, the creation of a community of practice, and the creation of opportunities for teachers to assume leadership roles. Rather than studying these teachers' leadership practices in situ (i.e. in their daily interactions with colleagues within their schools), however, the researchers accounted for their leadership development through the triangulation of data from interviews, observations of formal presentations and document analysis. Unsurprisingly, Howe and Stubbs (2003) argued that hierarchical administrative structures within schools isolate teachers from influencing cultural changes that lead to school-wide initiates that improve student-learning outcomes. Without school structures that encourage professional interaction and collaborative support – as evident in Mr Cresswell's school, for example (see Ritchie and Rigano 2003) – Ann Howe and Harriett Stubbs (2003) argued that it is unlikely that teachers will develop their leadership capacities.

The teacher leaders studied in New Jersey by Nancy Gigante and William Firestone (2008) also were graduates of a teacher leadership programme that prepared mathematics and science teachers for in-school leadership roles for curriculum reform. These teacher leaders performed two broad functions in their schools: support and development. While three leaders engaged in only support (i.e. managing materials or preparing laboratories, building confidence or generating enthusiasm, piloting curriculum), four engaged in both support and development functions (i.e. designing activities or lessons, answering content questions, modelling or team teaching lessons, facilitating professional development) functions. They argued that the interaction of four contextual resources was needed for teacher leaders to make a sustained impact on their teaching colleagues. These included time to interact and coordinate professional development activities, administrative support to reinforce the role of teacher leaders, relationships with teachers, and coordination and reinforcement of professional development. Interestingly, these researchers acknowledged the importance of individual or personal enthusiasm of teacher leaders, but did not recognise enthusiasm or group effervescence as a product of successful interactions (see Collins 2004). Nevertheless, they asserted that 'the improvement of teacher spirit can have far-reaching effects of retaining teachers and empowering them to improve their practice' (p. 312).

Canadian-based Brian Lewthwaite (2006) studied the experiences of three New Zealand teachers as they developed their capabilities as science teacher leaders during sustained school-wide science delivery improvement projects. These teacher leaders were interviewed via email about school-wide science delivery development projects in their elementary schools. As well as these interactions, all teachers at these schools responded to an online instrument called the Science Curriculum Implementation Questionnaire. Even though only one out of 49 items from the instrument mentioned leadership, the teacher narratives supported the following conclusions: collegial and professional support for the teacher leaders was important for the professional development of these teachers; and their development was dependent on personal, contextual and time factors.

Wayne Melville and John Wallace, also based in Canada, reported the leadership practices of four science teachers in one science department of an Australian high school (Melville and Wallace 2007; Melville et al. 2007). They analysed the individual teachers' interactions for adherence to assertions about teacher leadership from the literature. The results showed the teachers possessed dispositions that allowed them to accept positions as teacher leaders, and to contribute to the transformation of the department. In the case of each individual, Wayne Melville et al. (2007) argued that 'leadership was expressed through their engagement with different aspects of the departments' work. The net result of these expressions was that the department made significant changes to its practices over the period of the study' (p. 471). While the researchers declared the department was the unit of analysis, individual rather than collective leadership discourses were dominant.

Collective Perspectives of Leadership

Despite the hegemony of individualistic discourses in the leadership literature, James MacGregor Burns (1978) asserted that 'leadership is collective' (p. 452) because a web of relations are formed in organizations that bind leaders and other members in a social and political collective. As I show later, this does not devalue the importance of individual leaders taking action for the collective, but rather recognises that leadership is a relational construct that is not embodied in particular individuals. The term collective leadership is sometimes interchanged with related constructs such as shared and distributed leadership (e.g. Avolio et al. 2003). While I most recently have focused on collective leadership, others have focused on the theoretical development and application of distributed leadership.

As ‘critical friends’ to the principal and staff of a rural high school in Western Australia, John Wallace and Helen Wildy (Wallace and Wildy 1992; Wildy and Wallace 1997) observed significant cultural transformations to teaching and learning over a 6-year period that they attributed to ‘a greater emphasis on shared leadership, team building, consultation and responsibility among staff, often modelled in relationships with students’ (Wallace 2003, p. 5). A distributed perspective of leadership, John Wallace (2003) argued, shifts the focus from the traits and agency of valorised individuals to ‘structurally constrained conjoint agency, or the concertive labor performed by pluralities of interdependent organization members’ (Woods 2004, p. 6). De-centering the individual leader, a distributed leadership perspective ‘focuses on the interactions, rather than the actions, of those in formal and informal leadership roles’ (Harris and Spillane 2008, p. 31), with the practices being stretched over personnel and other resources within the school (Spillane et al. 2001a, b). Distributed leadership, then, empowers individuals and groups by concentrating ‘on engaging expertise wherever it exists within the organization rather than seeking this only through formal position or role’ (Harris 2004, p. 13).

James Spillane and his colleagues from Northwestern University (Spillane et al. 2001a, b, 2004) are well known for their studies of distributed leadership in Chicago elementary schools. They have found that the execution of most leadership tasks involves multiple leaders, and that the extent to which leadership is distributed depends on the subject area. Interestingly, they found that leadership activity in literacy involves more leaders than in mathematics and science. More importantly, the critical question that focused their attention in each case study involved how leadership is distributed within the school.

James Spillane et al. (2004) identified three types of leadership distribution. First, collaborative distribution underscores the reciprocal interdependencies between individual teachers playing or feeding off one another; that is, each teacher’s actions arise from interactions with other teachers that in turn fuel subsequent and continuing interactions. Second, coordinated distribution refers to tasks that teachers undertake separately or together in a coordinated sequence, usually where tasks are allocated and coordinated by the designated leader. Third, collective distribution is leadership practice that is stretched over two or more leaders who work separately but interdependently; for example, this would be evident in co-principalships where each principal agrees on and performs their task responsibilities.

Starting from James Spillane et al.’s (2001a, b) theoretical development, I conducted a critical ethnography of an academy in a large urban high school in northeastern USA with my colleagues Kenneth Tobin, Wolff-Michael Roth and Cristobal Carambo (Ritchie et al. 2007). Our theoretical standpoint considered the dialectical relationship between individual and collective leadership practices. For this reason, we moved away from identifying our position on leadership as distributed to avoid the inevitability of resolving the ‘distributed by whom?’ question, an important sticking point for us because the question assumes that, in organizations like schools, an individual is responsible for distributing leadership and ignores the possibility that collectives (e.g. teams of teachers) can engage in particular tasks jointly for the common good. We then returned to James MacGregor Burns's (1978) original notion that leadership was collective and proposed a tentative definition for collective leadership as the process by which members of the group, team, academy or school create structures[1] that afford the group accomplishing its goals. We noted that this definition was based in part on generalised social exchange theory (Seers et al. 2003) that 'describes an emergent pattern in which individuals exhibit group-directed behaviours that are reciprocated by other group members; … [It] is multi-lateral, indirect exchange in which individual contributions are spread over time and across various group members' (pp. 85–86). From this perspective, generalised exchanges are likely to build group solidarity (Seers et al. 2003) or a feeling of membership and belonging (see Collins 2004) because contributions are made with the expectation that returns will be spread over time and across members.

At the time of Stephen Ritchie et al.'s (2007) study, the Science, Engineering and Mathematics (SEM) academy was in transition after being formed from two previous academies in a school-wide restructure and where the designated leader of the academy (i.e. Cristobal Carambo) had just been appointed after the recent promotion of the previous leader to assistant principal. The academy appeared to be split between two factions, each led by a candidate for the vacated formal position of academy leader. Loyalties were split and there was a tendency for teachers to conduct their work privately in competition with each other for scarce resources rather than collaboratively where resources could be shared for the collective good. Over time, the academy became more cohesive as teachers started to trust each other by sharing resources for collective use in the academy. These resources were not limited to material objects and included ideas for teaching and management of the academy.

The new academy leader accessed and helped to disperse information about effective teaching practices in the service of the collective interests of the academy. For example, he recounted the practice used frequently by a female teacher who successfully established a home–school partnership to a male beginning teacher (i.e. Bryant) who was struggling to gain respect from his students. The teacher regularly contacted parents by telephone to inform them of the progress and achievements of her students. This helped to reinforce the positive work habits of the students at home, as well as establish an effective communication channel with the parents. Successful interactions among teachers and among teachers and students built a sense

[1] The term *structure* refers to the social arrangements, relations and practices that exert power and constraint over what individuals and groups can do, while *agency* refers to the power to act in social contexts by individuals and groups. The relationship between structure and agency is recursive because, through social interactions, each action reproduces and produces structures that become resources for further possible actions of participants. This dialectical relationship can be represented as structure|agency (see Sewell 1992).

of common purpose and belonging (or solidarity) among members of the academy, leaving them with positive emotional energy or enthusiasm to achieve new goals.

Sharing resources and ideas for teaching and learning need not be limited to an academy leader or teachers. In the SEM academy, students also contributed to discussions that focused on improving their learning. These discussions were named cogenerative dialogues because they were intended to cogenerate collective resolutions in regard to issues such as outcomes, roles, resources and rule structures within science classrooms. Typically cogenerative dialogues included the teacher and two or three students, with each having responsibility for ensuring that all participants contribute ideas without regard to formal status within the school, ethnicity or gender. They could also be used in meetings between administrative staff, parents and their children and in whole-class settings.

In one whole-class cogenerative dialogue that I observed, students were keen to suggest ways in which classroom procedures could enhance their motivation to engage in planned activities. After this meeting, both students and the teacher were committed to enacting the resolutions that were intended to improve the learning outcomes for the students and the teaching goals of the teacher. Successful outcomes from cogenerative dialogues encouraged students to exercise their collective agency in other contexts when teacher practices and academy/school structures interfered with their learning. On these occasions, aggrieved students respectfully requested participants (e.g. teacher and class) to engage in cogenerative dialogue to resolve a perceived problem. In this way, the practice of cogenerative dialogue became more widely used within the academy with greater commitment from the collective to effect agreed resolutions.

From our research in the SEM academy, we found it helpful to extend typical meanings of distributed leadership and refine our tentative position on collective leadership. We came to think of collective leadership as involving shared responsibility of members to enact structures that afford agency to stakeholders. As well, we realised that collective leadership manifests not only as practices like cogenerative dialogues, but also as solidarity among participants and the generation of positive emotional energy through successful interactions.

This refined position on collective leadership was applied by Stephen Ritchie and colleagues (2006) to the cross-case study of leadership dynamics of science departments in two culturally different high schools from a provincial city in Australia. Each department depended on the collective resources produced by individual and small teams of teachers for the benefit of their respective teachers and students. The department coordinators acknowledged the importance of drawing on these internal resources as well as utilising selected external resources for the purpose of improving practices within their schools. They accepted individual leadership roles while being receptive to suggestions and ideas from others within their departments, particularly in relation to the preparation of units of work by teachers. In this sense, the department structures enabled multiple leaders to influence each other mutually for the collective good. In many ways, both coordinators enacted collective leadership practices that empowered all teachers to lead. Yet, it was acknowledged that designated leaders such as department coordinators experience privileged positions that afford them differential agency in shaping structures that encourage or constrain teachers' contributions to shaping these structures.

Practical Implications of Collective Leadership

As seen in the studies of collective leadership in science departments (e.g. Ritchie et al. 2006), collective leadership can manifest as teamwork. Self-selected informal teams, involving teachers who share ideas and resources for the development of units of work, might form temporally. Alternatively, even in hierarchically structured schools, individuals such as department coordinators might formally convene a working party within or across the department to improve particular structures that might enhance student learning. In both cases, human potential required for team capacity building is released and accessed as resources for/by the team. Here teachers develop expertise by working together so that the leadership that emerges collectively is more than the sum of its parts.

As well as recognising that different structures between schools account for differential agency of teachers within schools to contribute to new structures, the following implications for designated teacher leaders (i.e. department coordinators) can be gleaned from these studies:

- Accept that leadership is not embodied within individuals but manifests in the interactions between individuals within collectives.
- Seek opportunities for teachers to contribute to important discussions about policy and practices so that individuals can access and share the collective human resources for the benefit of both individuals and the collective.
- Create structures that involve smaller teams of teachers to exercise greater agency of individuals and groups.
- Resolve contradictions through the enactment of cogenerative dialogues (or meetings between stakeholders to cogenerate collective resolutions; see Ritchie et al. 2007) so that individuals can exercise their agency to refine structures for the collective good.

Further Theoretical Development of Collective Leadership

As I alluded to earlier, it is difficult for me to embrace James Spillane et al.'s (2001a, b, 2004) stance on distributive leadership when they continue to refer to the leader–follower binary as an inevitable relationship in theorising leadership, particularly teacher leadership. In successful teaching teams, it is more likely that all teachers will 'lead' because they will contribute ideas and other resources to the team in order to advance the team's goals that in turn will feed back on their practice. This is very different from one teacher leading while the others follow, or even a kind of turn taking in which each teacher takes a turn of leading and following. Nevertheless, teaching team members will need to contribute (i.e. agency) and be receptive to new and different ideas and practice from their colleagues (i.e. passivity) for cultural transformation to occur. While my previous research with collective leadership has applied the structure|agency and individual|collective dialectics, it now seems that the agency|passivity dialectic might be just as important for further theoretical development of collective leadership within schools.

Wolff-Michael Roth (2007) asserted that *passivity* (and the associated concept of *passibility*, the capacity to feel, suffer and be susceptible to sensation and emotion) ‘is at the very heart of agency and yet it is curiously absent from theorizing in the social sciences’ (p. 2). He argued that passivity was central in explaining how constraints bring about differences between the enacted and planned curriculum in schools: ‘teachers are both agential and passive with respect to the ways in which the enacted curriculum unfolds. It is a collective process and product so that teachers also are subject to their conditions as much as they bring these about (and changes therein)’ (pp. 7–8). In relation to a successful cogenerative dialogue between a teacher and her students, for example, a student might identify a problem to which the teacher was ignorant but, upon hearing and understanding the issue from the student’s perspective (passivity) along with reinforcement from the other students present (collective agency), the teacher now works with her students (agency) to construct a joint plan for which everyone will be responsible for enacting. In so doing, all participants become attuned (or receptive) to how others perceive and respond to the new structures put in place, with this influencing their individual and subsequent actions.

To illustrate the recursive relationship between agency and passivity in collective leadership further, I turn to a planning meeting between Cristobal Carambo and the beginning teacher named Bryant during the transformation of the SEM academy, as discussed previously by Ritchie et al. (2007). When Carambo became aware (passivity) of escalating negative emotional energy in Bryant’s class, he convened (agency) a planning meeting with Bryant. Carambo himself had become aware of another teacher’s practice (passivity) of telephoning parents about their children’s progress. Carambo brought this practice to Bryant’s attention with the intention of improving Bryant’s relationship with his students (agency). As Bryant listened, he nodded in synchrony with Carambo’s rhythmic gestures and speech (passivity) before annotating the practice (agency) in his notebook, possibly for further action. Without opening himself up for a suggestion from Carambo that might improve his relationship with students, Carambo’s agential move would not have made an impact on Bryant and his practice. In turn, during the episode, Carambo detailed the practice as he himself became aware of Bryant’s growing receptivity to the suggestion, creating an opportunity for both Carambo and Bryant to consider how this could be enacted in his classroom (collective agency). Passivity and agency were both required for successful cultural change and for their collective leadership to transform practice in Bryant’s classroom and become a resource that other teachers within the academy could access and use. Through this post hoc analysis, and in light of this review, I can refine further my understanding of collective leadership. *Collective leadership is the iterative and recursive process in which members of a group, team or organisational unit share responsibility for the generation and enactment of structures that afford them agency and passivity for continuing successful interactions through which solidarity and positive emotional energy emerge.*

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Chapter 57
Understanding Scientific Uncertainty as a Teaching and Learning Goal

Susan A. Kirch

Current Goals for Science Education

A hallmark of science education in the twentieth century was the investment many countries made in the development of national standards for science teaching and learning. The US national science education content standards call for elementary school students to ask questions about natural phenomena, communicate about their own and their peers' investigations and explanations, plan and conduct simple investigations, use data to construct reasonable explanations, learn what constitutes evidence, and judge the merits or strength of the data and information that will be used to make explanations (National Research Council [NRC] 1996, pp. 121–122). Furthermore, the national science teaching standards call for all teachers of science to: (1) support inquiries while interacting with students; (2) orchestrate discourse among students about scientific ideas; (3) recognize and respond to student diversity and encourage all students to participate fully in science learning; (4) encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science; (5) encourage informal discussion; (6) structure science activities so that students are required to explain and justify their understanding, argue from data and defend their conclusions, and critically assess and challenge the scientific explanations of one another (NRC 1996). For upper elementary and middle school (grades 5–8), the content standards call for a sophisticated understanding of the nature of science including an understanding that scientific knowledge is both durable and tentative and why this apparent contradiction is reasonable (NRC 1996, p. 171).

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The science education standards require students to participate in conversations that address uncertainty or incorporate varying degrees of certainty. For example, according to the standards, once an investigation is conducted, students are expected to "use data to construct reasonable explanations" (NRC 1996, p. 121). What is "reasonable"? A reasonable explanation would be consistent with a larger body of evidence and tested understanding, within a range of uncertainty. There can still be cause for doubt about the way the investigation was done or what interpretations were made. It is the process of identifying what remains uncertain and why that determines whether it is a reasonable explanation. Uncertainty is a common state among learners in any field. For example, nearly every aspect of professional discussions among scientists features attention to uncertainty (Kirch 2008, 2010). Researchers such as Bruno Latour and Steve Woolgar (1986), studying scientists at work, have demonstrated that one major motivator for scientists is to generate a fair degree of certainty about a statement and much time and resources are spent resolving uncertainty. Henry Pollack argued that although nonscientists often equate science with certainty (owing to the presentation of science as a body of knowledge) uncertainty is one major driving force for scientists in their production of knowledge about how the world works (Pollack 2003). According to Tim Rowland, schoolteachers and children rarely acknowledge that uncertainty is a precondition for learning and a common, honorable state of being (Rowland 2000, p. 116). In research with students of all ages, the rules of the science classroom and the schema for science typically reward comprehension and conviction, not hesitation. Where uncertainty lies, and its magnitude, are neglected aspects of scientific inquiry in the classroom.

In the following sections, I (1) explore scientific uncertainty through the examination of an ongoing investigation and present a model for the types of scientific uncertainty and their sources, (2) argue that teaching about scientific uncertainty is educationally defensible, and (3) propose implications for the design and development of new teaching and learning tools to mediate student understanding of uncertainty in science.

The Case of the Disappearing Honeybees and a Model for the Role of Uncertainty in Science

In order to illustrate the pervasiveness of uncertainty in science and the accessibility of scientific uncertainty to the nonscientist, I draw upon a science story that was emerging at the time of this writing – the death of massive numbers of commercial honeybee colonies. At the moment, there are no conclusive answers to the central question, what is causing US honeybee colonies to collapse, and it is interesting to examine the uncertainties as they surface. For example, we can ask: What are the researchable questions? What are the data and do we believe them? Are there competing interpretations? What are the plans for further investigation? How is the research being used to inform the public? How should beekeepers use the scientific information they are receiving? Questions like these – questions that illuminate sources and types of uncertainty – have no place in current science curricula because current practices typically do not facilitate teaching and learning how scientific knowledge is constructed or how nonscientists should use or benefit from science knowledge.

Readers may be familiar with some of the media reports that described beekeepers' experiences of massive honeybee colony die-offs that threatened US agriculture (termed CCD, Colony Collapse Disorder). The headlines conveyed a sense of mystery, panic, urgency, fortitude, creativity, and complexity:

The case of the empty hives (Stokstad 2007)
Stung: Where have all the bees gone? (Kolbert 2007)
As bees go missing, a $9.3 billion crisis lurks (Stipp 2007)
Bees vanish, and scientists race for reasons (Barrionuevo 2007a, b)
Bees vanish, leaving keepers in peril (Barrionuevo 2007a, b)
Not-so-elementary bee mystery: Detectives sift clues in the case of the missing insects (Milius 2007)
Virus seen as a prime suspect in death of honeybees (Revkin 2007)
The mysterious deaths of the honeybees: Honeybee colony collapse drives price of honey higher and threatens fruit and vegetable production (Sahba 2007*).*

Science news reporters, (Erik Stokstad 2007; Elizabeth Kolbert 2007), described how beekeepers began to notice unusual, colony-wide deaths in the fall of 2006 and reported that one keeper, David Hackenberg, brought this to the attention of entomologists in November that year. By the following winter Diane Cox-Foster of the Department of Entomology at Pennsylvania State University testified to the US congress that the same symptoms had been reported in 24 states across the USA and in two Canadian Provinces (Cox-Foster 2007). Congressional representative Dennis Cardoza (2007) reported that the symptoms of CCD were unlike anything scientists and beekeepers had seen before. When researchers and beekeepers compared the current symptoms with collapses caused by known viral, mite, fungal and bacterial infections, they found little overlap. In CCD, bee colony populations declined rapidly from a strong colony with many bees to a nearly empty colony with few or no surviving bees. This disappearing phenomenon also had been seen in other countries, but only recently (Cox-Foster et al. 2007). Honeybee queens were typically found accompanied by a few young adult bees, lots of capped brood, and plenty of food resources (there was no indication of malnutrition or of robbery). No dead adult bees were found inside or outside the affected hives (the pathology for other known diseases includes dead bees found in and outside the hive, in the case of CCD they seemed to be flying away to die). Also, unique to this syndrome was the significant delay in robbing of the collapsed hive by other bees and pest insects suggesting the presence of a deterrent chemical or toxin in the hive (Cox-Foster 2007). Diana Cox-Foster, Ian Lipkin, and their collaborators at five institutions further reported that although researchers found correlations of CCD with the appearance of the Israeli Acute Paralysis Virus (IAPV), at the time of this writing, there is still no definitive proof that this virus is the cause nor is any preventative action advised (Cox-Foster et al. 2007).

Uncertainty in Planning Investigations

Science is a dynamic system of knowledge construction. This communal construction has mediating structures and procedures for producing, identifying, and resolving uncertainty. Outsiders can see and experience it by examining public records. By studying ongoing investigations, however, we can potentially participate in assembling the facts and determining appropriate actions and responses.

Given what is known about past colony collapse cases there was intense uncertainty and debate about the possible causes of the current trend when researchers and other stakeholders gathered together. The symptoms did not look similar to anything else seen before, and since there were so "few data on the health of domesticated honey bees – and even fewer on wild populations – many scientists aren't even convinced yet that what's going on is really a new phenomenon" (Stokstad 2007, p. 970). For instance, at the first meeting convened by the US Department of Agriculture (USDA) in Beltsville, Maryland biologists and entomologists were asked to devise a research strategy on CCD. This group of scientists proposed a variety of causes for the colony collapse including infections by known and unknown parasites and pathogens, bad weather that leave bees hungry, insecticides and pesticides sprayed on crop plants, and effects of industrial-scale beekeeping operations (e.g., diets that affect the circadian rhythms of the insects; stress induced from trucking around the country as migrant beekeepers chase spring blooms from south to north and west to east). According to Jeffery Pettis of a USDA bee lab, they had so little information from prior experience that they "proceeded [to make their recommendations for research] not knowing which causes might be more important" (Stokstad 2007, p. 970). With so many reasonable and consistent possibilities to explain the cause of the collapse, the CCD Working Group formulated several hypotheses to test. They focused on the following three questions: (1) Are new or reemerging pathogens responsible for CCD? (2) Are environmental chemicals causing the immunosuppression of bees and triggering CCD? (3) Is a combination of stressors (e.g., varroa mites, nutritional stress) interacting to weaken bee colonies and allowing stress-related pathogens such as fungi to cause final collapse? According to Cox-Foster, various interest groups (National Honey Board, USDA, Pennsylvania Department of Agriculture (PDA), Pennsylvania State University, US Department of Defense, and several beekeeper organizations) funded specialists in the areas related to the questions (e.g., infectious disease, chemical toxicity, and immune system function) in order to identify the cause of the disorder (Cox-Foster 2007).

Uncertainty Communicated About Peers' Investigations and Explanations

Given divided expertise within the community there is always potential for uncertainty about proposed cause/effect relationships. For example, in their publication of the results addressing whether a new or reemerging pathogen is responsible for CCD, Cox-Foster, Lipkin and their colleagues implicated a known virus (IAPV) as correlating with the appearance of CCD and they suggested that the IAPV may have been imported into the USA from Australia. They hesitated to declare that they had "proven a causal relationship between any infectious agent and CCD" (Cox-Foster et al. 2007, p. 288) because their experiments did not provide direct proof that IAPV infection causes CCD. Furthermore, there was only a weak correlation implying that the Australian imports were the original vector and the researchers were in the process of infecting healthy, IAPV-free colonies with IAPV to determine if the virus is capable of inducing CCD. In a letter to the editor, a scientist from the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia (Denis Anderson) and a government official from the Australian Department of Agriculture, Fisheries and Forestry (Iain East) contested the claim that IAPV was introduced to the USA via Australian honeybees given that IAPV was detected in the USA in 2002 (3 years before the first description of CCD). They also claimed that IAPV had not been found in Australian honeybees (Anderson and East 2008). Related to their objection are concerns (uncertainty) about the analytic methods used by the US researchers. Specifically, Anderson and East questioned whether the predictive model used to identify IAPV as a bee pathogen was consistent with conventions of research on pathogens. They also challenged the reported results with the empirical observation that Israeli bees infected with IAPV do not suffer from CCD. Anderson and East also disputed the claim that Australian bees imported into the USA were infected with IAPV. Cox-Foster, Lipkin, and their colleagues (Cox-Foster et al. 2008) responded to the criticisms with several pieces of clarifying evidence. Indeed, IAPV was found in Australian honeybee samples as well as in other samples from around the world. Cox-Foster et al. (2008) accounted for the discrepancies by explaining that their viral detection methods were different from those used in earlier studies and were more sensitive, therefore it was possible that prior detection methods were less reliable. Furthermore, the authors pointed out that although there were no reports of CCD in Australia at the time of publication, there were reports of a "Disappearing Disorder" that had not been described or explained adequately and may, in fact, be CCD. Drawing on the scientific community's developing understanding of the behavior of viruses, they also suggested that different lineages of the same virus could differ in their degree of pathogenicity, which would explain the variable appearance of CCD internationally despite the potential ubiquity of IAPV (Cox-Foster et al. 2008).

In the previous example, the main objections by Anderson and East were about interpretations and conclusions drawn by Cox-Foster, Lipkin, and their colleagues.

Uncertainty also commonly arises within the scientific practitioner community about what was done (experimental procedure), what was observed, and what was interpreted because of the way labor is divided within a research group(s). The division of labor among researchers in a group or between groups requires that the individual(s) who did not conduct the experiment establish a mutual understanding of the procedures, observations, and interpretations before they can communicate results to others or participate in drawing or judging conclusions based on the data gathered. Although the quality of work done by individual researchers in the laboratory is not typically featured in public accounts of research, a recent study by Kirch (2008, 2010) demonstrates that much uncertainty is a product of the division of labor that is now common in modern technologically specialized laboratories.

Uncertainty About the Merits or Strength of the Data and Information Used to Make Explanations

In the exchanges between Anderson and East, and Cox-Foster and her colleagues we see an illustration of uncertainty in expert judgment between two groups within the formal scientific community (knowledge producers). The entire community of stakeholders in this case, however, is comprised of both consumers and producers of knowledge. Uncertainty can arise between these groups due to differences in abilities to understand and utilize the data to build reliable explanations. For example, confused newspaper accounts reported that a group of German scientists was exploring cell phone signals as a possible cause of the disorder (Milius 2007). Jeffrey Pettis reported to Susan Milius that when he heard the report of the German research team he did not think it was a viable explanation because he rarely had cell phone reception when visiting afflicted hives in rural areas. When the German researchers credited with that line of investigation were asked to comment, it became clear that they were not studying CCD at all, but had been misrepresented by the reporter (Milius 2007).

Uncertainty About How Scientific Information/Results Should Be Used to Solve Real-World Problems

Some reports declared that irradiating hives (a procedure used to destroy viruses) has some protective effect, while other reports stated that CCD equipment should not be reused and should be burned. Despite the discrepancies in opinion and the inconclusive nature of the state of knowledge, practitioners are often quick to adopt potential preventative measures even before the scientific community sanctions these practices. How do we take imperfect knowledge and use it to make policy decisions? What is the best recommendation at this time, burning hives (an expensive proposition) or cleaning hives (inexpensive but, time consuming)?

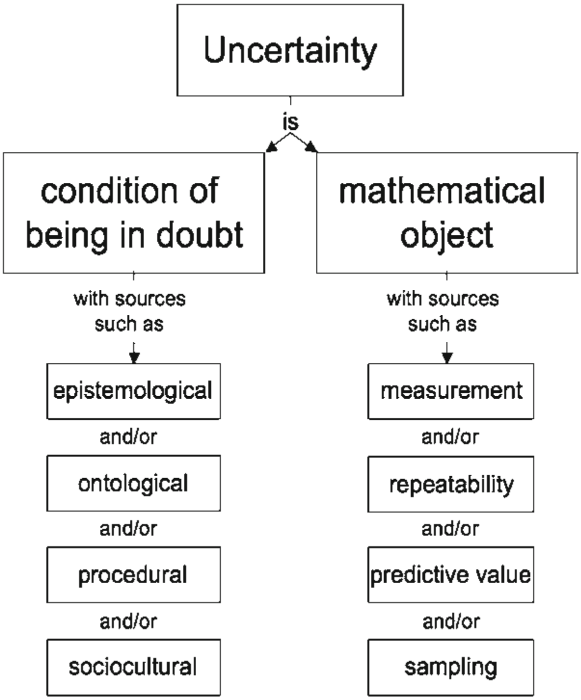

Fig. 57.1 A model for uncertainty and its sources

A Model for Uncertainty and Its Sources

At the time this review was written, the cause of CCD has not been determined. Overall, this illustration shows examples of scientists identifying and resolving uncertainty. The process of identification is ongoing and takes the form of asking questions, finding contradictions, or recognizing anomalous data and formulating questions that articulate uncertainty. Once questions and issues are identified, resolution requires conducting research and asking more questions. If we are interested in teaching students the role of uncertainty in scientific knowledge production and application, it is important to articulate a clear model or representation of scientific uncertainty. Uncertainty refers to a psychological condition of being in doubt (e.g., I am uncertain about something or someone…). It also refers to a mathematical object (e.g., a statistical estimation of uncertainty) as organized in Fig. 57.1.

As a mathematical object, uncertainty arises in measurement, sampling, repeatability, and predictive value. Douglas Currant-Everett (2000) proposed that uncertainty can be calculated for each of these four elements and include chance error (measurement), confidence intervals (sampling and repeatability), and logistic equations (prediction). When uncertainty is a psychological condition of being in doubt its origins can be procedural, sociocultural, epistemological, and ontological.

In the CCD illustration used here, doubts are voiced in the community about procedural practices (observations, methods, and interpretations). Although, the public documents contain no examples of overt doubt about the motives or abilities of the individuals conducting the experiments, the criticism of the Australians, Anderson and East, implies that the US scientists should be conscious of the socio-political consequences of their conclusions. The condition of being in doubt also can be an ontological position as illustrated by the stakeholders who continue to wonder if the collapse is something new or a contrived pattern and an inaccurate perception of reality. Finally, uncertainty derived from an epistemological source is always present and there were several examples in the featured study such as the quality of the viral detection tests and the characterization of disease symptoms.

Teaching and Learning About Scientific Uncertainty Is Educationally Defensible

In Angelo Collins' account of the development of the US National Science Education Standards, she agrees that documents outlining national standards for education are political documents (Collins 1998). The US National Science Education Standards clearly elevate content-transcendent goals of education (e.g., decision-making, philosophy of science, the sociocultural context of science, and the application of science) to the same level of importance as the process of science and the discipline-specific content of science. Stephen Norris (1996) advocates the use of these content-transcendent goals to help students achieve epistemic distance between themselves and science. Epistemic distance is defined as a "cognitive distance between hearing a claim to scientific knowledge and believing that claim is warranted: zero distance implies believing whatever is heard; infinite distance implies believing nothing" (Norris 1996, p. 253). I would add that an understanding of uncertainty would make epistemic distance an achievable aim and redefine it from the dichotomy of belief/reject to conditional belief (i.e., belief with variable uncertainty).

In Norris' evaluation of the feasibility of achieving content-transcendent goals in science (such as, the use of argument and evidence and the critical thinking strategies implied in the standards) he asks: "What is the nature and extent of the critical assessment that nonscientists can make of scientific knowledge claims and of their application? To what extent can science education promote such critical assessment?" (Norris 1996, p. 252). Norris suggests that future research will probably demonstrate that nonscientists cannot easily judge the data generated by scientists or how those data are then used as evidence to draw conclusions or generate explanations for natural phenomena. The implications of this predicted finding are that science educators should not aim to have students judge and interpret scientific evidence or sources. Norris also suggests that with appropriate research we will find that nonscientists cannot judge the reliability of scientists unless they are explicitly taught strategies for judging those knowledge-generating sources.

Instructional time is precious and there are many special interest groups competing for that time. What should we advise for the instructional time allocated for science? Many have proposed that we teach nonscientists to make decisions about how science is used to solve personal and social problems. Since the development of Dewey's progressive philosophy of science and the Science, Technology, Society (STS) movement of the 1960s, several science education researchers have proposed that one of the main goals for science teaching and learning should be to ensure that students know how to use scientific knowledge to solve practical problems. Derek Hodson (2003) advocates for a curriculum oriented toward sociopolitical action. Wolff-Michael Roth and Angela Calabrese Barton (2004) agree and propose teaching critical scientific literacy in school classrooms designed to allow a variety of participatory modes. Stein Kolstø (2001) outlines topics that can serve as resources for students to examine science-related claims in socio-scientific issues and Gaell Hildebrand (2006) calls for "critical activism," which requires learning how to: "identify salient claims, analyze assumptions, be skeptical of evidence sources, evaluate alternative perspectives, seek warrants for conclusions, distinguish between belief and evidence, and so on" (Hildebrand 2006, p. 58). Still others support the inclusion of controversial, socially relevant issues within science curricula (e.g., see contributions in Zeidler 2003). The types of decision-making in these recommendations regarding "proposed applications of science fall squarely within the interests of nonscientists" and acknowledge that scientists "have no special expertise in the moral, prudential, economic, aesthetic, or other grounds that bear upon the justification for an application of science" (Norris 1996, p. 255).

How and to what extent can nonscientists be expected to distance themselves epistemically from claims made in the name of science and can they learn/acquire this distance through a science education program that focuses on evaluating and justifying proposed applications of science to real-world problems? I propose that teaching students cultural resources for understanding, identifying, and resolving uncertainty is a practical approach to achieving many of the desirable content-transcendent goals in science (Kirch 2010) because, (1) uncertainty is pervasive and not limited to science, (2) the identification and resolution of uncertainty is essential for production of scientific knowledge, (3) assessing the applications of scientific knowledge requires the identification and resolution of uncertainty, and (4) uncertainty explains how all scientific knowledge can be simultaneously durable and tentative.

Henry Pollack (2003) points out that uncertainty is not confined to the world of science; it is also an inescapable feature of everyday life. Every day people wonder: Will it rain today? Will a sick passenger delay the trains? In addition to short-term possibilities that are uncertain, Pollack reminds us that there are long-term uncertainties (e.g., will my retirement fund support a comfortable lifestyle) and uncertainties about the future as well as the past. In spite of the fact that we are surrounded by uncertainty in our daily lives, we are used to responding and taking action (uncertainty, however, can impede rational action).

Although we all manage short- and long-term uncertainties about the future and the past on a daily basis with varying degrees of success, anxiety, or stress, Pollack observes that we are reluctant to "take actions addressing complex science-based issues in the face of similar levels of uncertainty" (Pollack 2003, p. 2). He suggests that this is, in part, because we feel inadequately prepared to identify and respond rationally to the scientific uncertainty associated with these issues (e.g., global climate change; vaccination policy; energy policy; fishing and farming policy). Pollack argues that nonscientists should "understand and accommodate scientific uncertainty in much the same way that they deal with other uncertainties in life" and that they should feel "that scientific uncertainty should cause no greater hesitation or doubt than do the multitude of other uncertainties the people regularly face and routinely accommodate in their lives" (Pollack 2003, p. 4).

How can science educators teach students how to understand scientific uncertainty? Teresa Crawford et al. (2000) showed that if students do not have opportunities to participate in "student-initiated science explorations under the conditions of uncertainty and for topics in which the teacher lacked relevant disciplinary knowledge" (p. 237), they would not be able to acquire the cultural resources "necessary to make scientific decisions and direct their learning" (p. 240). Students should learn how to use the results of scientific research and recommendations from the scientific community to work with all community members (scientists and nonscientists) for rational decision-making and action; a learning activity that can result in students developing and expanding their agency – their power to act in the world. Crawford, Kelly and Brown (2000) view uncertainty as a cultural resource and assert that understanding the role of uncertainty is something students struggle with as they learn about science. Although students have difficulty with the concept, this does not imply they cannot learn it or that teaching and learning strategies cannot be improved. Studying uncertainty in science is a way that students can learn how to understand the conditional statements that the scientific community places on knowledge. In the next section, I explore what resources need to be developed for teaching uncertainty.

Teaching and Learning Uncertainty Will Require High-Quality Cultural Tools

Regardless of the recommendations put forth in science education reform documents, there is overwhelming evidence that for the last 20 years science has been taught primarily as a body of knowledge. In the most recent examination of science learning environments of primarily middle-class elementary school students conducted by Robert Pianta and his colleagues, the quality of instructional climate received a low rating due to the lack of "rich instructional methods" and "evaluative feedback" given to students (Pianta et al. 2007). Observers documented that instruction engaged students in only one method or mode of work (e.g., filling in a worksheet or watching a demonstration), and teachers' feedback to students focused on correctness of student responses rather than the discussion of alternative solutions and extension of performance. "Few opportunities were provided for students to learn in small groups, to improve analytical skills, or to interact extensively with teachers" (Pianta et al. 2007, p. 1796). Observations and ratings were similar in all grades examined (1st, 3rd, and 5th grade).

It is uncommon for current curricula to engage young children in authentic scientific inquiry where students learn to be skeptical and open-minded, to reconcile the apparent contradiction of the durable and tentative nature of scientific knowledge, and to recognize the place of uncertainty in scientific understanding. Science is typically presented to children as facts and word-concepts to be learned. This trend continues from elementary school (Pianta et al. 2007) to middle school (Kesidou and Roseman 2002) and in high school (Groves 1995). Kathleen Metz describes this phenomenon as the "decomposition and decontextualization" of scientific inquiry and argues that it has repercussions for the image of science as a way of knowing (Metz 2004, p. 221). Sofia Kesidou and Jo Ellen Roseman (2002) demonstrated that none of the nine widely used science education programs in middle school support teaching and learning the key disciplinary ideas present in the US standards for science education. Fred Groves (1995) analyzed the science vocabulary load of high school textbooks and found that students are exposed to more vocabulary than found in foreign language classrooms.

Such approaches to elementary science education are based on the commonly held view that children are concrete and simplistic thinkers, which is then used as a justification for a lack of emphasis on teaching higher-order generalizations (including scientific thinking and methods) in elementary school science curricula (Metz 1995). Metz argues that this lack in school science curricula, paradoxically, leads to the very features of students' thinking that serve as a presumed rationale for teaching them disconnected (and often simplistic) facts and skills in a piecemeal fashion (Metz 2004). Similarly, Anna Stetsenko and Igor Arievitch (2002) have proposed that, hidden in the context of traditional teaching methods common in school science, there is a self-perpetuating cycle driven by inadequate theories of development. These inadequate theories lead to contingent educational practices, which lead to poor developmental outcomes for students. These poor outcomes serve to confirm the inadequate theories of child/human development, which reinforce educational practices that fail to improve developmental outcomes for students (Arievitch and Stetsenko 2000; Stetsenko and Arievitch 2002).

What are the implications for teaching content-transcendent goals such as an understanding of scientific uncertainty and the role of uncertainty in knowledge generation? The same as for all learning goals – that teaching, learning, and cognitive development are mutually dependent and mediated by culturally evolved cognitive tools.

> Cultural tools are not static "things" but embodiments of certain ways of acting in human communities. They represent the functions and meanings of things as discovered in cultural practices: they are "objects-that-can-be-used-for-certain-purposes" in human societies. They can be appropriated by a child only through acting upon and with them. Such reconstruction of cultural tools is initially possibly only through interaction with other people who already have the knowledge of a given cultural tool. (Stetsenko and Arievitch 2002, p. 87)

It may be obvious to point out that cognitive development is tightly linked to teaching and learning, but the nature of that link is not appreciated widely (Stetsenko 2008). According to Stetsenko and Arievitch (2002), "teaching leads development because it allows children to learn to use new cultural tools, and such mastery constitutes the very cornerstone of mental development" (p. 88). The current practice of science education (and probably other areas of education) does not reflect this relationship. If students are routinely expected to know (and rewarded for knowing) the facts, ideas, and concepts of science, and the mechanism for learning this is by rote memorization, then they are not learning the cultural tools for any aspect of science (whether it be organizing content or understanding content-transcendent organizing generalizations).

Post-Vygotskian curriculum developers have explored and experimented with structures and methods of teaching and learning in mathematics (e.g., Davydov 1990; Lompscher 1999), science (e.g., Giest and Lompscher 2003; Hedegaard 1996), history (e.g., Hedegaard 2002), and language arts (e.g., Aidarova 1982; Haenen 2001). These researchers have outlined essential elements for designing tools for teaching and learning within a sociocultural theoretical framework that recognizes the interdependence of teaching, learning, and cognitive development. The element that is consistent with all their approaches is that learning is based on "ascending from the abstract to the concrete" (Davydov 1988, p. 66). That is, whenever possible, students should be presented with and oriented toward conceptual analyses of the problem and general principles at the beginning of problem solving. This approach is considered teaching in the zone of proximal development because it orients students toward learning general principles as the means for them to solve problems. The general principles are abstractions with which students may have difficulty but will learn through application to empirical examples. In Marianne Hedegaard's pedagogical approach, for example, teachers generate the general principles or essential generalizations to be learned and design the problems with which students will interact to apply the general principles and form new principals (e.g., Hedegaard 2002). In the goals for science education presented here, the general principles are the content-transcendent goals for science education. If students are oriented toward these general principles, the motivation for learning scientific knowledge changes from memorizing key ideas to building a general system of knowledge within a community of participants that communicate and use that knowledge for various purposes.

The model of uncertainty outlined here can be used to orient students toward the typical sources of uncertainty as demonstrated in the CCD discussion and summarized in Fig. 57.1. General sources of scientific uncertainty can be categorized as mathematical, ontological, psychological, and/or epistemological and include: uncertainty in investigation planning, uncertainty expressed within a community about investigations and explanations, how rules and schema shape uncertainty, uncertainty as a product of the division of labor and uncertainty about application of scientific information. Once students are oriented toward these general categories and types of uncertainty within a curriculum that allows for the discussion of anomalous data, decision-making on personal and social issues using scientific information, and other contextualized activities, will they be able to identify, resolve, and analyze their own use of uncertainty? Will they be able to consider contemporary, unresolved questions in science and understand how uncertainty shapes the emerging knowledge? Will they be able to identify and resolve uncertainty related to controversial issues that involve scientific knowledge? To the extent that we can answer these questions in the affirmative is a measure of our success as science educators.

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Chapter 58
Citizen Science, Ecojustice, and Science Education: Rethinking an Education from Nowhere

Michael P. Mueller and Deborah J. Tippins

Introduction

We live in a time of profound change in which a pastiche of cultural identities and influences define our postmodern society. As in the movie *The Matrix*, today's youth live in multiple and changing lifeworlds where new symbolic meanings are created on a daily basis (Tippins 2008). Consider, for example, Kyunying, a Hmong child whose family recently immigrated as refugees after living for 20 years in a postwar detention camp. Kyunying has quickly become part of a complex Pan-Asian urban community where she watches Tai movies, eats Chinese food, and listens to hip-hop music.

Amidst our twenty-first-century flattened world, where people are in constant motion, the classroom is quiet, but the neighborhood is buzzing with the rising tensions of young citizens.[1] These tensions include academics, athletics, bullying, alcohol and drugs, purchasing power, sex, and pregnancy, to name a few. Young citizens

[1] For the purposes of this chapter, citizens are defined as those who are stakeholders in their communities. All citizens play a role as stakeholders in the commons (Mueller 2008a) by embodying ways of knowing, beliefs and values, and expectations – a group of individuals who are embedded within larger ecosystems. Even as Western philosophers attempt to deny the rights of women, children, slaves, and the natural world, they are equal moral subjects with differing characteristics but nonetheless individuals in relation to others. Citizens may be affected parties without a voice, marginalized individuals or groups, insiders, and outsiders. Ecojustice reminds us that citizens are constituents of personal and collective experiences, who pay selective attention to some assumptions which frame their relationships with other citizens and the Earth. The unborn are also perceived as citizens for those who wish to protect the prospects of future generations. Likewise, Earth's other species are considered equal moral subjects with differing characteristics (Mueller 2009), which is an extended ideal of citizens of the Earth, and rights for the natural world to reproduce.

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are constantly making decisions and they seek out parents, teachers, friends, and other mentors, to help guide their way. Along the way, they witness tensions for adults, for example, the multidimensional challenges of economic and political instability and trying times for the environment. Youth witness with less tainted lenses, as adults in their communities increasingly wrestle with trade-off decisions that range from too few agricultural and natural resources to where to invest economic resources. These trade-off decisions are grounded by the democratic practice of citizen involvement. Citizens become informed so that they can participate more fully and advocate for affected others or the biodiversity of the Earth. But these principles of participatory democracy and civic responsibility are seldom the priority for youth, especially in light of the way in which schools are structured and measured which presumes "an education from nowhere." The point of this chapter is that youth are already engaged as citizen stakeholders in the community, and consequently, they make decisions that impact the world. Science teachers should play a large role in their development as active participants in the community in relation to the Earth's landscapes.

In the spirit of the ancient proverb that encourages teaching of how to fish rather than simply giving out fish, we explore the emerging citizen science movement, and focus on how the health of a community or natural environment is indicative of school achievement instead of the science literacy of students.[2] Teaching students how to fish is rethinking the priorities of an education from nowhere where youth travel from science class to science class on a standardized journey of science concepts and facts. In this chapter, we explore why an education from/for somewhere should correspond with plural or relational positive endpoints emphasizing healthy community and environmental outcomes. These outcomes, however, are not yet favored by existing educational accountability mechanisms, for it is still much easier to quantify and communicate adequate yearly progress (or AYP). Consequently, science teachers are generally not rewarded for going beyond the regional, national, and international priorities of quantifying scientific literacy, which is based on an elevated status for academic achievement (e.g., Trends in International Mathematics and Science Study, National Center for Educational Statistics 2007). Perhaps there should not be an either/or. But given the priorities of testing and more testing, there is very little time for going beyond the status quo. While one might argue that higher test scores enable higher degrees of participatory democracy and civic responsibility, achievement scores were only marginally related in a recent study by Joseph Kahne and Susan Sporte (2008). These scholars note: "Indeed, focusing on teacher, student, and peer relationships associated with academics and social development appears insufficient as a means of fostering commitments to civic and political engagement" (p. 755). Other scholars concur (e.g., Youniss and Yates 1997).

[2] For the purposes of this chapter, scientific literacy is initially defined as appreciation for and understandings of what professional scientists do (Hurd 1998). This definition is reflected in the Cornell University model, and embedded within the science education reform documents (AAAS 1993; NRC 1996). We connect with other scholars to reevaluate the appropriateness and significance of this conceptualization.

For low-income students and students of color, who generally have less of a voice in policy decisions and yet are disproportionately affected by adverse environmental conditions, de-emphasizing citizen development and civic responsibility in light of scientific literacy (as an elevated priority) in schools is especially destructive.

Emphasizing science concepts and facts that students like Kyunying should know, rather than how they can get involved in participatory democracy and civic responsibility creates the presumption that teachers are exclusively preparing youth to become citizens when they are already young citizens who contribute much to the world. Around the world, the youth of today are already engaged in aboriginal education, adventure education, citizen science, community-based education, democratic education, ecological and environmental education, experiential learning, multicultural education, outdoor education, place-based education, and community and environmental service learning pedagogies. These different pedagogical strategies typically share a common goal of increasing scientific knowledge and skills, understanding of the natural world, geographic awareness and ecological literacy, and ethical care for biological and physical environments. They have emerged as a way of helping citizens to be more involved with their community and ecosystems (Chopyak 2001), going back to the basics of citizen participation and democracy (Mueller and Bentley 2007), community capitalism (Kitchens 2008), and shared activism (Boyd 2001).

From a practical standpoint, the above pedagogies admirably address civic development of youth. They share a common altruism in preparing students to engage the competency of their environments. But, they differ with respect to theoretical justifications, which in turn, provide the reasons why educators should embrace and value a particular approach versus another. There is an emerging emphasis in science education on engaging youth in citizen science as an appropriate and significant method of cultivating civic development (e.g., Jenkins 1999). The underlying claims for citizen science, supporting logic, and practical examples are interesting from a philosophical standpoint. Moreover, the framework for citizen science in science education is important for any researcher, teacher, community volunteer, and so forth.

In the next segment, we highlight how citizen science is conceptualized in science education. Then, we explore some justifications for engaging youth in citizen science and some challenges for science education. We argue that citizen science contributes to ecojustice, and explain why it ought to emphasize the health of communities and natural environments in relation to others, as a way to measure achievement. We differ from others scholars and the major US science education reform documents such as the American Association for the Advancement of Science (AAAS 1993) and the National Research Council (NRC 1996) by downplaying the veracity of scientific literacy as the overarching goal for science education and defend the position that the health of the local community and natural environments should take priority in the schools. We further show that citizen science supports ecojustice (Bowers 2006), environmentalism (Mueller 2009), and renewed interest, which makes a difference that matters worldwide.

Citizen Science

More than 3,900 plant species are being monitored by citizen scientists who are collecting careful observations of phenological events such as the first bud burst, first leafing, first flower, seed or fruit dispersal of a diversity of trees, weeds, ornamentals, and flowering species in different parts of the USA.

Morten Creek, a salmon-bearing creek in North Vancouver, British Columbia, Canada is being restored, as citizen scientists work in a small hatchery building for spawning and care of Coho and Chum. A long-term amphibian monitoring effort established by the National Wildlife Federation (NWF) involves over 4,300 citizen scientists learning to identify frog calls, habitats, breeding and activity patterns, so they may participate more fully in surveying frogs and water quality and contribute to an NWF databank.

According to the 2008 Citizen Science Toolkit (Citizen Science Toolkit Conference 2008), a comprehensive citizen science clearinghouse on the Internet (see Resources), there are over 200 citizen science projects that have been identified worldwide. So-called citizen scientists are predominately involved in monitoring environmental indicators and biodiversity related to regional climate change, which range in scope from the micrometer to the cosmos. Examples of citizen science projects include monarch larva and butterfly migration monitoring, ant surveys, worm and weed watches, lake ice, weather, municipal water quality, and a plethora of bird surveys. Still others involve international inquiry and pen-pal correspondence between cities where neotropical birds migrate or where very diverse vegetation food sources and habitats encourage interesting species adaptation (Our Shared Forests Program 2009). Early efforts at citizen science in the USA can be traced back to 1722 and the 16-year-old Benjamin Franklin who wrote under the pseudonym Silence Dogood (Woody 1931). Franklin found it a serious mistake that educational institutions did not instruct youth in ways that were authentic, meaningful, and relevant to their everyday life. Although Benjamin Franklin is one of the early citizen scientists who collected weather data, the first of two official surveys in terms of birds, began with counting the large number of birds that whacked into lighthouses in the 1800s (Droege 2007). A second was initiated by Wells Cook, a traveler, school teacher, and professor. His survey organized people to study bird migration, a program that ran from the early 1800s to the mid-twentieth century, and generated an astounding 6,000,000 records with thousands of citizen scientists. Other historical citizen science projects include several hunter surveys and waterfowl parts collections, and the Audubon's Christmas Bird Count which was initiated at the turn of the twentieth century and which celebrated its 109th count with tens of thousands of citizens surveying early-winter bird populations from December 14, 2008 to January 5, 2009. But what follows are several citizen science projects that have been highlighted in the education literature.

Ornithologists collaborating with science education researchers at Cornell University have been dedicated to promoting scientific inquiry through the development of citizen science curriculum materials, partnerships with middle school and adult volunteers, design of instructional guides, observation protocols, and scientific databanks for housing bird counts, Classroom FeederWatch (CFW) data, and nesting surveys (e.g., Trumbull et al. 2005). For these scholars, the meaningful purpose of engaging in authentic science through citizen science projects and partnerships with professional scientists is to develop an appreciation for and understanding of what professional scientists do. By analyzing over 700 letters from adult citizen scientists participating in bird feeder preference surveys, for example, Deborah Trumbull et al. (2000) identify that nearly 80% of participants revealed indicators of scientific literacy and some alternate conceptions as well. However, Deborah Trumbull et al. (2005) find that CFW demonstrated marginal understandings of scientific inquiry for middle school students. They suggest that curriculum materials more aligned with the National Science Education Standards (NRC 1996), specific science content knowledge, and explicit instruction of what professional scientists do, may have led to targeted understandings of inquiry. In the hopes that citizen scientists' attitudes toward science and the natural environment would be affected by participation in The Birdhouse Network (TBN) project at the Cornell Laboratory of Ornithology, Dominique Brossard et al. (2005) analyzed the investigations of adult volunteers who put up one or more bird boxes in their yards, and were then asked to observe and report on clutch size of each nest, calcium intake of birds, and nest site selection. The participants received "detailed explanations of the scientific protocol to be followed, biological information about cavity-nesting species, and practical information concerning nest box design, construction, and monitoring" (p. 1102). In other words, very explicit science instruction. Subsequently, these findings demonstrate a statistically significant change in participants' knowledge of bird biology, but no significant change in attitudes toward science or the environment, or understanding of science process. Interestingly, the results of the pretest data suggest that the volunteers selected for this citizen science project were already highly concerned about environmental conservation, and they already were highly motivated in this project by their interest in local birds rather than their involvement in science. These results are reinforced by other scholars who have shown that civic responsibility is generally higher for citizens who are motivated by the welfare of their local community (Jones and Colby 2001) or status of their biological and physical environments (Evans et al. 2005). These studies beg the question: Since studies demonstrate that volunteers are predominately motivated to engage in citizen science projects because of their interest in the welfare of birds and the environment, then why is the predominate goal of engaging youth in citizen science focused on developing scientific literacy?

Challenges for Citizen Science

Science education for citizen development may be different from science education for the appreciation for and understanding of what professional scientists do. We already know that there is a need for increased and more equitable levels of civic participation and that science education can do much to meet this need. For example, the NRC (2007) report on the North American pollinator decline suggests citizen science where science teachers and students are recognized for the contributions they can provide for the scientific community. The NRC calls for high-intensity biodiversity surveys, and notes, “the assessment should include monitoring of pollinator status and function that integrates the work of professional scientists and citizen-scientists to maximize the depth and breadth of effort” (p. 10). Moreover, the NRC calls for the conservation and restoration of pollinator friendly habitats, such as wildflower gardens, as well as the public outreach and education needed “to raise awareness of pollinator’s ecological and economic contributions and to encourage public participation in conservation” (p. 11). The NRC notes “as part of their outreach, federal granting agencies should make an effort to enhance pollinator awareness in the broader community through citizen-scientist monitoring programs, teacher education, and K–12 and general public education that center on pollination” (p. 11). Correspondingly, the *Great Sunflower* citizen science project (Phillips 2008) was designed this past spring 2008 to monitor and map bee populations in response to colony collapse disorder (or CCD), which is devastating for honeybee populations across the USA. However, the citizen science proposed could go farther to ensure that the science produced by teachers and students will go beyond the margins and will be taken seriously when important policy decisions are being created.

The Cornell University model of citizen science embodied in large-scale bird monitoring projects aforementioned are criticized for a top-down approach to generating data, where a team of scientists and educators determine the research questions, investigation protocol, and who will be included (Ely 2008). While a top-down scientist-driven approach is good for covering a lot of turf, the citizen scientists are limited to collecting data while professionals and managers design and test the protocols, analyze volunteer contributed data, and publish results. This approach also limits the amount of time that professional scientists will be out in the community collaborating face-to-face with citizens (Evans et al. 2005), which is a challenge identified for Cornell’s model (Ely 2008). Additionally, a top-down model of citizen science may reinforce the silencing and misrepresentation of teachers and students much in the same way that conventional models of educational research privilege perspectives of policymakers or administrators. If citizen scientists are to be recognized for the appropriate and significant questions they wish to generate and the types of investigations they wish to pursue in response to the health of their communities or environments, then scientists need to play a different role of inquiring alongside citizen scientists rather than dictating agendas. The dynamics of power differentials between (novice) citizen scientists and professional scientists are much more likely to limit students’ experiences and growth when top-down, scientist-driven citizen science is employed, as evidenced by the pitfalls of participating in this established community (e.g., Hogan 2002). If the priority of science education is to develop scientific literacy, then top-down citizen science may work and a heightened awareness of the power/knowledge problems that can potentially stem from top-down approaches may be overlooked. We do not want to be misunderstood as promoting hierarchies. Contrasting views are just as important for developing our understandings of scientist-driven agendas in relation to community-driven ones. However, community and environmental problems seldom have universal causes. If the priority in schools becomes the health and welfare of the local community and environment, then local solutions should be sought. These solutions may occur everywhere but there is a need to focus on democratizing science, methods, and equipment at the local level (e.g., a watershed). More analysis is needed to determine whether top-down or bottom-up citizen science is better equipped for some goals of science education which contribute to how community members nurture others and ecosystems where they dwell. Now, we analyze this with respect to a theoretical framework.

A Theoretical Framework for Citizen Science

We will first argue that science first needs to be democratized by repositioning it as something to which all citizens can contribute. In the best of current worlds, teachers teach students what they need to know to navigate the dominant cultural milieu, get into college, obtain financial support, and enter the workforce. But many teachers feel torn between what they need to do to help youth succeed and relying on their own autonomy as professional educators to help students learn to address and resolve problems in their lives. Without the latter, the youth of today, citizens in a rapidly globalizing world, feel a sense of depression and hopelessness, and even feel out of control. If not careful, teachers may implicitly teach students that their local knowledge, face-to-face conversations, narratives, cultural traditions and ceremonies are not as important as the standardized curriculum. The idea may be implicitly conveyed that local problems will be solved by scientific and technological advancement.

More recently, ecologists such as Carol Brewer (2002) and Louis Gross (Brewer and Gross 2003) along with Rebecca Jordan, Frederick Singer, John Vaughan, and Alan Berkowitz (2009) have emphasized the need for stakeholders with multiple perspectives, including ecojustice ethics, to increase degrees of confidence associated with decision-making and policy. However, K–12 students may not be considered as citizens yet and their perspectives may not be as highly valued as the adults in the community. Likewise, youth may be considered too immature to make such important decisions as what aspects of the bioregion should be conserved and where already limited financial resources should be allocated. But youth are very attracted to exploring the natural world, and in some cases, they are more sensitive to the changes occurring within diverse environments. In fact, young citizens may serve as the only advocates of particular plants and animals, especially when some species lack elevated economic worth (Aslaksen and Myhr 2007).

Can youth be trusted for the quality of their investigations and resulting data? A growing number of science educators (e.g., Fogleman and Curran 2008) are finding that their watershed data can be used effectively when scientists and teachers play an active role in guiding youth inquiry (Fore et al. 2001). A great example is Florida's LAKEWATCH program (Canfield et al. 2002) and other stream survey sites (Engel and Voshell 2002). Throughout his career, Jonathan Kozol (2005) explains that he has been criticized for relying too heavily on students' narratives in his scholarship. He says, "I have always found that children are a great deal more reliable in telling us what actually goes on in public school than many of the adult experts who develop policies that shape their destinies" (p. 12). Youth generally say it like it is. They do not have ideologies to reinforce. They do not promote a political agenda. They are not worried about civic equanimity. They do not have a reputation to uphold. They have few reasons to mislead us on the big things, even as they may err on the specific. They need to be recognized for their astute observations, collective knowledges and local skills, and personality. Kozol has been an educator and researcher for more than 40 years and he continues to trust the powerful narratives of children. If all citizens have an equal shake at participating more fully in the decisions where they live, then today's youth might be valued for their less-than-tainted ways of knowing and observing. Now the potential of including students as legitimate citizens of the local bioregion begins to take shape. Yet even as students are viewed as equal citizens, science teachers need to cultivate geographic knowledge where they live so that today's young people will not lose sight of places. Without these geo-knowledges, teachers together with their students may not have the collateral needed to be involved in local decisions.

The metaphor of "decorated landscapes" (Mueller and Bentley 2007, p. 1) has been used to defend the idea that solely preparing youth for economic interests is sorely short-sighted when compared with the goal of preparing students to live as reflective, reliant, and reciprocal citizens with each other and other species. If youth are considered citizens embedded in ecologies, then we should focus on their ecological pluralism, such as gender, class, race, ethnicity, and diverse geographies. When science education is reconceived as reflective, reliant, and reciprocal of citizens and geography, then one major incentive of doing science is to preserve cultural and environmental spaces and the empowerment gained from being recognized as experts. For science teachers and their students, this acknowledgment positions them as indispensable in the decisions of the community. Adversely, when educational reforms privilege standardized curriculum, young people are *dis*placed as citizens. The educational priority of *dis*placing citizens by privileging the same everywhere takes acknowledgment away from students and degrades the natural environments where they live; for it is not possible for these citizens to be inhabitants nowhere. Education from nowhere displaces citizens so efficiently that when students' cultural and environmental spaces are de-emphasized or ignored, they must rely on the market for their survival. Measures of displacement are immediately apparent when the market is not as accessible as it once was. One example is Hurricane Katrina in 2005.

With the lack of longer-term evidence, the majority of pollinators remain unprotected by the Endangered Species Act of 1973 (ESA) – they cannot be listed as threatened or endangered because the ESA exempts any insect that can cause economic damages. However, these pollinators are essential to about three-quarters of the more than 240,000 species of the world's flowering plants and enable the cultivation of over 90 different agricultural crops (NRC 2007). Recognizing humility in the face of uncertainty, there continue to be instances where trade-offs linked with genetically modified organisms and toxins, with few exceptions, will carry the far-reaching consequences of abrupt plant extinctions, economic hardships for farmers, and declines in the food supply, medicines, wood, and fibers. Without cultivating local knowledges, how will citizens know when to take appropriate actions on important ecological issues?

A significant roadblock to cultivating citizens in the places where they live is the current view of scientific literacy, which suggests that science teachers and students are the consumers of science and scientists are the producers of science (Hurd 1998). Paul deHart Hurd argues that students who wish to become scientifically literate need to recognize "scientific researchers as *producers* of knowledge and citizens as *users* of science knowledge" (p. 413, emphasis in original). This concept of scientific literacy seems fine if the goal is top-down scientist-driven citizen science for larger-scale studies. But the role of citizens as the "*users* of science knowledge" is too restrictive for the community-driven citizen science, or methods advocated here. Scientist-driven undermines the democratized contributions of science teachers and students who wish to be recognized as members of science communities. When students are required to be consumers rather than producers of science, an implicit message is conveyed that what is learned is always more important than how it is learned. Science is something that people do, not just the people with the professional hats. The scientific literacy proposed by Hurd could go farther to enable science teachers and their students to be positioned as authoritative and important sources of democratized scientific knowledge.

Scientific literacy as proposed by Hurd may be *re*placed through citizen science – a growing interest for science educators (Eisenhart et al. 1996). According to Wolff-Michael Roth and Angela Calabrese Barton (2004), when students engage in citizen science, they participate through multiple relations and situations in which science is enacted in the community. They differ from Hurd (1998) in that they propose scientific literacy with a postmodern taint which positions the science institution within the sociocultural situations between individuals at work in the community and the environment. Dana Fusco (2001), in her work with teenagers in an urban gardening project, invites teachers and students to participate in a practicing culture of science learning where children "draw on as well as define science, its activities and uses within a specific context for special purposes" (p. 862). Similarly, in Southeast Asia, Filipino and US science educators are collaborating to create a community-centered science teacher preparation which emphasizes students, children, teachers, and community members as coproducers of science that both emerges from and reports to the community it is designed to serve (Nichols et al. 2006). This cultural approach to scientific literacy acknowledges that science teachers and students represent the culture of science in many different ways and it takes seriously the multifarious relationships when and where science is enacted. It also prepares science teachers and students to embrace and value the significance of contributing to the welfare of the region in relation to others. This kind of community and environmental agency helps to cultivate diverse knowledges from within localities where teachers and students live. Because local knowledges may not be represented elsewhere, science teachers and their students can participate more fully, which helps them to be taken more seriously by policymakers.

Correspondingly, Wilson (2006) suggests that citizen science is the knowledge that any person interested in understanding the ecological world can partake. Wilson highlights examples of citizen science in the success of the All Taxa Biodiversity Inventory (ATBI) of the Great Smoky Mountains where scientists, educators, students, and other members of the community work together to investigate species distributions, habitat interactions, population sizes, and the life cycles of organisms. The ATBI is the kind of citizen science project where the science knowledge and skill produced by citizens is taken seriously by ecologists, biogeographers, and conservationists. It is this diverse geographic knowledge that makes science teachers and students indispensable. Wilson developed a worldwide *Encyclopedia of Life* (see http://www.eol.org/index), where theoretically, everyone will be able to contribute their studies to a databank. This databank will then be used to track the impact of climate changes and other ecological trends, along with regional knowledges. When science teachers and students are recognized as contributing participants in the scientific enterprise, they become better positioned to participate more fully in the decision-making of the community. Scientific data are increasingly being made more available on the worldwide web, from sea turtle and bird migrations, to real-time earthquake monitoring and volcano activity logs. These datasets can be analyzed by science teachers and students and then compared with the scientific work occurring around the world. They are not limited to the geographic knowledge of the Earth (Mueller and Valderrama 2006), and in similar digital multimedia information-spaces there is the potential for citizen scientists to be in greater positions of agency as they co-construct knowledge in nonlinear ways.

Most citizen science theory admirably recognizes that science teachers and students (and other community members) are participating members of an extended scientific community. Teachers and their students become aware of what data are needed and supply these data, at any appropriate level of quality, and they are taken seriously. Any decision-making process is constrained to answer one or more particular question, and specific data are needed for this purpose. If the question has to do with Monarch butterflies and genetically modified corn, then data on salamanders or hummingbirds may be irrelevant and, thus, useless for the intended purpose. The matter of data-acquisition, which is more or less equivalent to how scientists collaborate on investigations with stakeholders, needs to be explained by the decision-makers such that citizen scientists can gain meaningful involvement. When citizen scientists complement the needs of the local community and ecosystems, they will be acknowledged as citizens who participate more fully.

However, this collective praxis of science, community, and environment may still privilege the power of top-down, scientist-driven approaches to citizen science. What has not been discussed is the challenge of how this collective praxis de-emphasizes or marginalizes personal and collective experiences with other Earth species (recognizing that even the term species is controversial in biology), including deeply embedded beliefs and values, and both private and public interactions, as part of ecologies. The cultural residue of normal science may permeate the thinking of science teachers and students who perceive science through the collective praxis where the normal institution remains the basis for relative measures of success, comparison, and scientific literacy. Humanizing science or citizen science that democratizes normal science may be perceived as token science (Aikenhead 2006), which penalizes any science that deviates from the norm. The thrust of citizen science defined by somewhere is the community and the process of working outward rather than inward in ways that contribute to the physical and emotional strength of the local environment. It is also a process that is relationally important such that citizen scientists work alongside each other to generate ideas and policies at a community level. In this view of education, there is an inherent assumption that all things exist in relation. An explicit recognition of this assumption is needed to ensure humility, harmony, and balance – but not sameness – as advocates of the local environment and community we often meet on common grounds. As with any ideology, we must ultimately be aware of the danger of creating rigid categories for observations to fit within, rather than being democratized by citizens (Jenkins 2006). This modification to citizen science requires rethinking an education from nowhere and prioritizes nurturing opportunities for communities and ecosystems in relation to others where science education for citizen development is illuminated in research, theory, and pedagogy. That is, a nurturing opportunity project is one effort of continuous revitalization of the once fully cared for (Roth and Lee 2004). We posit, therefore, that a project of science education for citizen development is closely aligned with the humility needed to protect multiple perspectives (and ethics) in the face of uncertainty that surely influences how science educators begin to address advancements in ecojustice, environmentalism, and sustainability as the meaningful purpose of engaging stakeholders in citizen science.

Implications for Science Education

In a study focused on the Ecological Explorers (EE) program in Phoenix, Arizona, researchers Deborah Banks et al. (2005) find that more than 75% of teachers attending EE workshops offered throughout the year and communicating with project coordinators, use science protocols for collecting data (e.g., arthropods, beetles, seeds, birds, vegetation, and neighborhood) in their classrooms within a year of training. Almost 50% of teachers have students uploading data for intra-school comparisons within the first 2 years of the program. The vast majority of teachers are supported by the school administration, and also state that they share their training with school colleagues. More than 80% of teachers integrate the EE program as a way to teach scientific inquiry, which meets the US national and state priorities associated with standards-driven science education. However, the teachers note the challenges of integrating the EE program because of other competing demands for addressing the school's curriculum, the emphasis on knowledge standards, difficulties accessing equipment and insufficient time to develop students' higher-order reasoning. One of the most interesting aspects of the Banks et al. study is that the majority of students are from underrepresented groups (i.e., more than two-thirds Latino). In summary, Banks et al. note that "the results of our study suggest that programs like EE aim to build learning communities within and among schools and between the schools and a university or college" and "the larger picture of knowledge about the importance of ecosystems and ecosystem services so that participants can become more informed about environmental policies and citizen responsibilities" (pp. 661–662).

In another article, Backyard Ecology (Elser et al. 2003), a teacher describes her experience integrating the EE program into the science education curriculum while meeting state standards and accomplishing her own classroom goals. She notes that 145 students are involved in an open-ended project with the community. Her students study how to collect bird data and eventually present their class work in a poster session, which she suggests is representative of their personalities – a key ingredient for fostering ecological literacy in schools. The teacher notes that students become more excited about learning science, which is evidenced by students coming in before and after regular class time to work on the project and by students sharing their knowledge with friends and family when outdoors. She considers this community outreach. She notes that the project has a ripple effect in that it generates "interest from other students and teachers as well" and that students connect "with research taking place at the local university" and learn that the school is "a habitat for all types of creatures, not just humans" (p. 45).

The EE program is just one of many examples of school initiatives shifting toward participatory democracy and civic responsibility in science education. Some implications for science education follow. First, today's students are keen on the degradation of local communities and environments. They are no longer prompted to sustained action by the threat of an impending ecological tragedy, catastrophe, or crisis. As teachers begin to realize the ways in which youth increasingly frame their relationships with others and the natural world with ecological metaphors more aligned with environmental trends in the USA and abroad, they will capitalize on students' knowledge of a local farmer's market or community supported agriculture (CSA), for example, as appropriate and effective pedagogical content knowledge (PCK) in their instruction. These ecological metaphors may be further enhanced by engaging students in citizen science, which stir culturally mediated assumptions and experiences for the meaningful learning of other science concepts. But here is the kicker. Theoretically, these assumptions will be more aligned with participatory democracy and civic responsibility and thereby offer a way to brew citizen stakeholders from early ages on into adulthood.

There are benefits when students are engaged in citizen science in ways that have less adverse affects for communities and ecosystems in terms of community reliance instead of reliance on the market. One could easily design, construct, and build the necessary materials for citizen science projects. Eliciting knowledge and skills needed to design and sew dip nets for a stream investigation, for example, encourages students to problem solve what kind of thread, cloth netting, recycled materials are appropriate and best. People in the community are generally responsive to youth who seek out the intergenerational knowledges needed to make materials for doing science because today's youth are so eager to reject these skills in light of rapidly increasing technological advances that deem their knowledges as old-fashioned and backwards. Dip nets, pitfall traps, and so forth, might be invented by students which makes science more entertaining, and which contributes to the democratization of science equipment, methods, and protocol for experiments. Perhaps local knowledge and skills can be renewed and revitalized in the community by involving youth in citizen science which both further develops youth citizens and reciprocally develops mentoring relations. This level of authenticity and meaningful interactions, along with students' motivation, in citizen science is surely heightened when the community is part of the process of deciding what problems need to be tackled, what equipment can be locally designed, and what methods and protocols will guide scientific inquiries.

The tenets of citizen science have important methodological implications for research as well. In contrast to a rational, technical process of identifying problems, applying theory to interpret the situation and behavioralistically enacting a prescribed solution, researchers seeking to better understand what citizen science might look like as an organizing framework for science education, must navigate contextual landscapes. These contextual landscapes include cognitive, social, cultural, political, and moral situations that uniquely intersect in the community. Researchers must observe and consider a kaleidoscope of personal histories, expectations, misinterpretations, adventures, and struggles which dynamically challenge the health of an ecosystem. They must be prepared to listen to and value the local narratives, many of which may embody emotional, aesthetic, or even spiritual qualities. In many cases, these narratives convey dynamic, complex, uncertain, and heartfelt discussions beyond conventions of formal discourse. While recognizing that different kinds of questions will be asked by local citizens, educational practitioners, and university researchers, some questions that might serve as a nexus for collaboration:

- What are the local narratives of a community and how do they change over time?
- What are the cultural tensions associated with the local narratives of the environment?
- How can we frame inquiries from a local perspective?
- How can citizens develop sustained interest in nurturing the health of ecosystems?
- What role do communities and environments play in science teaching and learning?

These questions will differ depending on the community and environments in which they are derived, and yet a common goal of paying closer attention to how we frame our relations is rich with research directions.

Much of the research for citizen science supports an idea that students become problem solvers, whereas students are more likely to contribute to the health of the community if involved in the community. The same is true of students' involvement in the environments, or ecosystems, in which they are embedded. Youth learn more deeply when they can apply knowledge learned in these contexts to authentic situations; they are more likely to take part in projects they design (i.e., sustained engagement and collaboration); and they will be more successful when they are taught how to learn in addition to what outcomes are expected. More importantly, citizen science provides a medium for developing meaningful relationships with other people in the community and with the Earth's flora and fauna. It is a relational pedagogy of becoming better informed, participating more fully in systematic decision-making, and advocating for affected others. Students, teachers, parents, and so forth (or communities and environments in which we are all embedded), are the benefactors of citizen science when Earth's citizens can nurture the welfare of geographic locations.

One might argue that citizen science is the same as contextual teaching and learning theories. Perhaps it is so for previous conceptualizations of citizen science. But there is a significant difference for this theory of citizen science. Inasmuch as citizen science supports ecojustice, it must be guided by ecojustice, ethics, and sustainable relationships. Wendell Berry (2000) notes the following which emphasizes this point.

> The world and its neighborhoods, natural and human, are not passively the subjects of art, any more than they are passively the subjects of science-industry-and-technology. They are affected by all that we do. And *they* respond. The world does not exist merely to be written about, any more than it exists merely to be studied. It is real, before and after human work. What we write is finally to be measured by the *health* of what we write about. What we think we know affects the *health* of the thing we think we know. (pp. 87–88, emphasis added)

In other words, part of the competency of engaging youth in science education for citizenship means developing justice, morals, and right relations with others and Earth. The health of what we write about and the health of the thing we think we know cannot remain *dis*placed in science education if we wish to protect the prospects of future generations. Everything exists in a dynamic, heterogeneous and evolving cosmos. Youth are already citizens within these evolutionary ecologies. Education beyond nowhere will recognize these things and make efforts to nurture them. Acknowledging the importance of ecojustice, environmentalism, and sustainability in science education is a start and will foster continued conversations.

One final comment before our conclusion: Science education for citizen development, or citizen science, might be criticized as an ineffective strategy for dealing with nowhere education without large numbers of science educators (and teachers from other disciplines) committed to working toward this idea. The standardization priorities of curriculum and schooling might seem like impossible odds to overcome. But citizen science cannot depend exclusively on the numbers of successful movements. It is often the few who really make a difference by embracing and valuing the health of a community and the ecosystems of the Earth. Clearly the longer-term accomplishments of healthy communities and environments will surpass current efforts to overemphasize the standardization of nowhere education. The success of the few is what has ever made a difference, for example, those who participated in Civil Rights movements of 1960s. In a similar vein, those who emphasize citizen development and responsibility alongside the health of communities and natural environments in science education will play a significant role in multiplying the longer-term effects. While the emerging ideas of citizen science may be met with scrutiny, they also may be elaborated by paying attention to the prospects of future generations, to affected parties without a voice, and to the Earth.

Conclusion

Scientific literacy is embedded within participatory democracy and civic responsibility. For citizen science then, the shape and scope of science education becomes one of participatory democracy and civic responsibility, and ultimately, the knowledge and skills needed to participate more fully in regional action. Global advocacy for affected parties and other species on Earth, and physical environments are definitely part of this enlarged agency. But teachers and students like Kyunying must be recognized for what they can ultimately contribute as citizens and stakeholders in the particular. They ought to be afforded the freedom and professional autonomy to think about how to address local situations in relation to larger global ones. Taking account of the ways that educators will collaborate with members of the community to effectively guide youth decision-making offers promise for sharing a responsibility for democratizing science and the uses thereof. There are still challenges ahead. Citizen science research, theory, and practice needs to address time and curriculum constraints, perceived outdoor risks, and the negotiation of effective learning, to name a few. Without these examinations, citizen science could easily dismiss the importance of multiple perspectives, methods and criteria, expectations, beliefs and values, and narratives, which are now needed to confront decisions about sustainable practices, what should be conserved, where resources are allocated, and what sorts of justice and ecological relationships should be cultivated to promote healthier community. Because we cannot avoid the decision to act, the time is here, the choices are shared, what will be decided?

List of Resources

The *Citizen Science Toolkit* is the most comprehensive clearinghouse for news, project ideas, and resources in support of citizen science projects worldwide (http://www.birds.cornell.edu/citscitoolkit).

Citizen Science Canada is an online community for people involved in environmental monitoring (http://www.citizenscience.ca).

The *Society for Amateur Scientists* is an organization to support citizen scientists (http://www.sas.org/).

The Citizen Scientist is a published bi-weekly by the Society for Amateur Scientists (http://www.sas.org/tcs/).

A *Citizen Science Weblog* that connects citizen scientists with the latest news, archival weblogs, citizen science by category, multimedia, and comprehensive articles on upcoming events, equipment and resource books (http://citizensci.com/).

Dynamic Patterns Research Institute supports and guides citizen science, and offers educational references and opportunities to engage in authentic scientific investigations (http://research.dynamicpatterns.com/).

National Aeronautics and Space Administration mentoring and inquiry using NASA data on atmospheric and Earth science for teachers and citizen scientists (http://mynasadata.larc.nasa.gov/citsci_index.php).

The *US Youth Network for Sustainable Development* is an organization to support young people advancing sustainable development and youth empowerment in the USA, with a citizen science paper competition, listserv, and partnership building (http://sustainus.org/content/view/16/128/).

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Chapter 59
Change – A Desired Permanent State in Science Education

Hanna J. Arzi

Science education is often described in terms of "in crisis," "at a crossroads," or "in need of reform," which raises the question: What has happened to projects that intended to fix the preceding crises, provide orientation at crossroads, even revolutionize education? Unfortunately, not much research exists on what actually happens over the long term. This reflects difficulties in sustaining any study over an extended period (Arzi 1988). Historians David Tyack and William Tobin (1994) noted that chronicles of reforms are particularly scarce when success could not be claimed: "There is a rich paper trail of such reforms in the advocacy stage, when people make ambitious claims for them, but when they fade, silence ensues. Because success is often equated with survival, few people have bothered to chronicle transitory innovations" (p. 455). Over the decades, however, data on educational change programs have accumulated. Not many wins could be declared, results were often described as inconclusive or lukewarm, and descriptors used to sum up change programs included figurative expressions, such as "faded away," "sunk," "got lost," or simply "failed," leading to studies on change programs being labeled as "Misery research" (e.g., in Ciaran Sugrue (2008), following earlier use of this label in the policy literature to lament the results of research on policy implementation or the quality of this research, or both). All in all, the available evidence shows that fundamental, sustainable, and widely distributed educational change is inherently difficult, sometimes impossible to achieve. The challenge of science education is augmented by the fact that it does not operate in isolation, but within schools and education systems with agendas that do not always attend to, and sometimes even interfere with, well-intended attempts at change in, or by means of, science education. If so, why even try?

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The intended message of this chapter is that change should be conceptualized as a permanent state – an infinitely ongoing condition; neither a discrete act or event, nor a process with an endpoint. Despite repeated attacks on the status quo, bothering issues persist in science education and keep reemerging, though sometimes in modified versions with shifted emphases and new jargon. Yet, past efforts left imprints which have gradually accumulated into significant improvements and a set of lessons for the future. Even much maligned programs, like the school science curricula of the 1950s–1960s, made long-lasting contributions. Borrowing the metaphor from the title *Tinkering toward Utopia* of David Tyack and Larry Cuban's (1995) book on school reform: Science educators have been tinkering toward Utopia, and while our ambitious grand goals are probably impossible to reach in full, we have been getting closer and will continue doing better, provided that change as a desired permanent state becomes the norm.

To substantiate my message, I scan cases of attempts at change in different contexts illustrating the persistence of yet unresolved issues of two types: persisting target issues – what to change; and persisting process issues – how to change. Prior to attending to change cases and issues, the chapter starts with notes on the choice of *change* as the lead superordinate concept. The chapter then goes back in time to the Eight-Year Study – an exemplary attempt at change in the USA during the 1930s. The presentation of this study serves as the organizer for discussion of current projects dealing with issues that I believe will continue to be of concern to science educators in the years to come.

Change as a Superordinate Multidimensional Concept

Change is often used as a slogan, a buzzword expressing a wish for something new and better. Dictionary definitions, however, refer neutrally to "something different," like the core sense of change in the *New Oxford Dictionary of English* (Pearsall 1998): "an act or process through which something becomes different." Accordingly, change can be for better or worse, large scale or small, short-lived or long term, planned or unplanned. This chapter attends to improvement-oriented planned change, including nonexplicitly intended outcomes of original plans (to be distinguished from unplanned change, such as aging or seasons of the year).

In parallel to change, the education literature uses the labels innovation and reform, even revolution. Change is the more inclusive concept, since innovation usually applies to the introduction of a single novel method, idea, or product, while reform is typically associated with large-scale programs aimed at institutions or practices (social, political, or economical). The concept revolution, too, is subsumed under change, and, anyway, its use in education cannot be often justified, as implied from its dictionary definition: "a dramatic and wide-reaching change in the way something works or is organized or in people's ideas about it" (Pearsall 1998). Because it is a superordinate concept, change can be applied equally to a government-initiated reform that aims to revolutionize education by spreading from center to periphery and top-down to each school, as to a modest innovation of a single teacher in a single classroom that may or may not exit the classroom door and grow bottom-up. *Change* is, therefore, this chapter's lead concept.

Dimensions of Change

Across different cases, I will attend to three major dimensions of change: spread – ranging from small to large scale; depth – from shallow to deep; and time – from short-lived to sustained change. No consensus exists as to the number of dimensions, their labels, definitions, and relative importance. For example, Cynthia Coburn (2003) identified four dimensions: three with similar meanings to those suggested above and a fourth dimension that refers to a shift in reform ownership in top-down reforms. Another example of variation is the division between incremental and fundamental change. This division is emphasized by Cuban (1993) without explicit mention of a dimension labeled depth, even though incremental change has features of the shallow end of the depth dimension, while fundamental change has features of its deep end. The latter categories emerged from an adaptation to education of ideas on change in human affairs presented by psychiatrists (Watzlawick et al. 1974) who used the terms "first-order" and "second-order" (parallel to incremental and fundamental, respectively). In another context and with other meanings, two and three orders of change appear in the business administration literature with regard to organizational change (Burke 2008).

Among the dimensions used to examine change, the extent to which a change is deep or fundamental is particularly difficult to estimate, though it is easy to tell in extreme cases when an action is shallow, or is merely administrative restructuring unlikely to result in pedagogical transformation. Spread seems easiest to measure in terms of project participant numbers (schools, classrooms, teachers, students). But actual commitment varies across participants and both numbers and extent of involvement often fluctuate over time. Furthermore, it is necessary to attend separately to spread in two periods: during the lifetime of a project – when human and material resources are mobilized; and beyond it – when concerted efforts are over and accomplishments are expected to sustain, perhaps also to scale up. Therefore, attention only to spread is of limited value unless it is interrelated with the dimensions of depth and time, as will be elaborated through illustrative cases.

The Eight-Year Study: An Old Story with Persisting Issues

The Eight-Year Study was an attempt at fundamental change in American secondary education during the 1930s. Eight decades later, it still stands out: aiming at pedagogical improvement through long-term inquiry, having democratic group leadership of true believers, establishing collaboration between academics and practitioners, and integrating a strong evaluation component that provided continual support to schools along with data on the study as a whole. While not a project in science education, it addressed cardinal issues in education that are relevant to science education. Likewise, obstacles to change that were present then continue to challenge us now. The persistence of issues and the qualities of this old study made me choose it as the lead case of the chapter.

The Eight-Year Study was chronicled throughout its progress, culminating in a five-volume final report (highlighted as exceptional documentation in Seymour Sarason's (2002) reflections on reforms). My presentation draws primarily on historical works that analyzed the original materials with a time perspective: the comprehensive inquiry of this enterprise by Craig Kridel and Robert Bullough, Jr. (2007), and sections attending to it as part of the twentieth-century history of American schools (Cuban 1993; Tyack and Cuban 1995). Another major source is the report by Frederick Redefer (1950) on his retrospective follow-up, *The Eight Year Study …. After Eight Years*. Because there is overlap between these and other sources, I refrained from interrupting the text by references, unless I make a specific quote.

Overview of the Eight-Year Study

The study grew from the progressive education movement, beginning with a decision made in 1930 by the Progressive Education Association to focus efforts on instilling the progressive spirit into secondary schools. Compared with primary schools, secondary schools were more traditional, entrenched within teacher- and subject-matter-centered pedagogy, and resisting shift toward student-centered approaches. This was largely blamed on the domination of colleges over schools by means of admission requirements, yet it was unclear how to proceed even if this obstacle would be eliminated. With a belief in experimentation, the decision was to resolve the issues via inquiry. Thirty school sites in 11 states volunteered to join in, and 284 colleges agreed to admit the program's graduates based on school recommendations, without external requirements. Actual school participation started in 1933 and ended in 1941; members of the leading team continued until the final report volumes were published during 1942, so the study spanned 12 years beyond the initial decision in 1930.

The study stated a twofold goal: "to establish a relationship between school and college that would permit and encourage reconstruction in the secondary school"; and "to find, through exploration and experimentation, how the high school in the United States can serve youth more effectively" (Aikin 1942, cited in Kridel and Bullough 2007, p. 3). In reality, the study focused on the second part of the goal that entailed debates on what it means to serve youth and what were the student needs that school should serve. Fights between reformers advocating priority to personal needs and those in favor of social needs had been going on before the 1930s (Jackson 1992). Contrary to debates within a one-sided child-centered view that were typical of progressive pedagogues, leaders of the Eight-Year Study also held an appreciation for academic subject matter and wished to explore experimental programs toward less traditional, more progressive education, "without compromising any student's chances of a successful college education" (Taylor 1932, cited in Kridel and Bullough 2007, p. 5).

Schools were encouraged to find their way without top-down imposition of concrete instructions, yet with a commitment to evaluation, combined with support by quality consultants. In practice, schools turned to curricular work and the vision of national reconstruction of secondary education thus became largely translated into a study on school-based development of local programs. Efforts concentrated on innovative modes of integration of academic school subjects, nonacademic areas, and informal activities. Accomplishments included breaking of traditional time frames, significant collaboration among teachers, and involvement of students in planning and evaluation processes, as part of their preparation for democratic citizenship. When they reached college, graduates of the study schools were found to do as well as graduates of traditional schools and some analyses showed that they were doing even better.

The study ended when funds ended, but ending was a process driven by both external and internal forces. Historians link its end, similarly to its beginning, to major events that bound the study on both sides: the Great Depression at its start, and World War II when it was fading away. In the early 1930s, with a poor economy and limited employment opportunities, more students tended to stay at high school, yet less enrolled in college. Consequently, high schools had to address new social challenges and respond to the needs of a more heterogeneous population. These circumstances favored nonconservative ideas that facilitated the initiation of the Eight-Year Study, including the agreement of many colleges to remove their admission requirements. But this was over when priorities changed due to World War II. Within schools, the internal opposition to the study that had existed all along was augmented by general conservative trends; furthermore, the cumulative staff turnover was substantial, and participating teachers gradually became exhausted by years of a demanding study. All these were part of the winding down process.

The Eight-Year Study Across Change Dimensions and Persisting Issues

Looking at the study along its spread, depth, and time dimensions of change enables an understanding of some of the complexities and virtues of this seemingly failed enterprise, and provides a clue as to why change target and process issues persist.

All the schools volunteering to participate, apart from one, stayed in through the 8 years. However, there was not full teacher participation. Consequently, for example, due to insufficient collaboration there were individual teachers who could just revise a single course, rather than cross borders of school subjects. The wide range of commitment led the evaluators to categorize schools into "more experimental" versus "less experimental." When the study officially ended, development efforts stopped and innovative materials with their related practices started disappearing.

The dependence of the different extents of spread on whether participating schools or committed teachers were counted, and the commitment drop after the study, are linked to the depth and time dimensions.

The study set out to explore how to reach lasting fundamental change in secondary school pedagogy and found that even under favorable conditions the process was slow and achievements were partial. This became visible at an early stage, for example, a school director complained about "ineffective 'tinkering' with the traditional college entrance requirements instead of actually [attending to students'] needs as adolescents" (Giles et al. 1942, cited in Kridel and Bullough 2007, p. 148). Redefer's (1950) follow-up study found regression to old practices of initially promising signs, including practices that became "a perversion of the original idea masquerading under the label" (p. 34). Using Tyack and Cuban's words, the Eight-Year Study "had a short (but happy) life before curriculum and pedagogy returned to traditional patterns" (1995, p. 63). Tyack and his colleagues (Tyack and Cuban 1995; Tyack and Tobin 1994) linked the regression in this and other attempts at sustained deep change to the organization and culture of schools which had been fortified over generations to provide stability. They captured this intangible obstacle through their "grammar" metaphor: The persistence of the grammar of schooling counteracts change. Somewhat similar are the metaphors of the "core" of educational practice that stays unchanged (Elmore 1996), and of the overarching "script" that dominates routine behavior (White 2003). Thus, surface features of school can be modified, practices scratched, and incremental patches added, but fundamentally, more often than not, things stay much the same.

Were the 8 years of the study insufficient to overrule the grammar of schools? In the absence of research evidence from longer school-reform projects that set out to move away from ingrained practices, we can only speculate. But despite failing to achieve its grand long-term goals, significant contributions are revealed if the time dimension is scanned beyond the formal end of the study. Redefer (1950) reported on teachers who did not fully abandon their newly acquired progressive classroom practices and instilled them into their traditional repertory. This observation was supported in the historical research of Cuban who referred to it as the formation of "hybrid" pedagogies that sustain over time (1993, 2009). The Eight-Year Study had further long-term effects on teachers' work by renewing their energy and leading some to become "active participants in education" (Redefer 1950, p. 35). Lasting contributions were also made to educational theory, research, and practice through the study's innovative evaluation under the leadership of Ralph Tyler (1949), whose seminal curriculum rationale is rooted in this enterprise. Members of Tyler's team went on to take central positions, thus extending ideas and knowledge; one of them, for example, was Lee Cronbach (1989) who acknowledged the long-term influence of this early experience.

Persisting Issues

Were the goals of the Eight-Year Study unattainable to start with? The point in raising this question is not to join in any ideological debate over progressive pedagogy, but to draw attention to aspects of the clarity and attainability of change goals. In regard to progressive-pedagogy-driven goals I will only mention that the child-centered view of learning was described as "romantic" (Labaree 2004), and that Joseph Schwab (1959/1978) criticized "Dewey's evangelists" for presenting teachers with simplistic distorted views, and attached the label "impossible" to the role of the teacher in progressive education. According to Kridel and Bullough (2007), however, leaders of the Eight-Year Study did not advocate an extreme progressive view but searched for a balanced position. The fact remains that major issues with which schools and teachers grappled in this study have been reappearing – yet unresolved. Common to many issues is that they present us with dilemmas: Issues have remained unresolved not just because the right strategies were not employed, but because they are complex and many do not have consensual solutions.

The persisting target issues include grand questions on the purposes of school and the wish to cater to *all* needs of *all* students, and challenges like enhancement of active student learning along with inquiry-oriented instruction or integration of disciplinary academic subjects. These issues that appeared in the Eight-Year Study in the context of general education in America of the 1930s, have been recently highlighted in the international arena of science education, as part of a list compiled by Peter Fensham (2008) in a document commissioned by UNESCO, entitled, *Science Education Policy-Making: Eleven Emerging Issues.* Some aspects of these persistently *reemerging* issues are visited below.

Cases of Change in Science Education

Unlike the Eight-Year Study, the following long-term cases occur in non-American contexts. Their longevity is an indicator of success – of course with varying extents of struggles, compromises, and criticism. They are different in their settings, goals, and strategies. I selected them for their common longevity and different features that allow me to highlight several persisting issues. Obviously, my selection of cases and what I focus on in each also reflect my predilections.

School-Based Assessment in Queensland: Opportunities with New and Old Hurdles

External examinations have been under attack for more than one reason, including perpetuating old practices. The case of school-based assessment policy in the Australian state of Queensland shows that, despite difficulties, it is possible to transfer responsibilities to school teachers, thus opening opportunities for change in classroom pedagogy. There are examples of states where internal school assessment occupies various proportions of student achievement results that count for entry to tertiary education, but Queensland is a rare case since assessment has been fully school-based for 4 decades.

The history of Queensland's assessment policy was evolutionary with several nodal points (I draw primarily on Eddie Clarke's (1987) historical study). Starting in 1824 as a penal colony, the first high schools in Queensland opened during the 1860s, with curriculum and assessment dictated by tertiary institutions in other Australian states until the establishment of its first university in 1909. University domination over secondary schools was largely unquestioned until the 1960s, when economic and social changes made the school population larger and more heterogeneous; consequently, it became obvious that prevailing practices giving priority to university-defined excellence were unsatisfactory. Debates, suggestions, and patchy actions eventually led to the recognition that a radical change was necessary. Thus, in 1970, when a special review committee came with the revolutionary recommendation to replace external examinations by school-based assessment, it was generally well accepted and officially adopted. Implementation, however, was problematic, with criticism across the board, inter alia, in regard to the reliance on norm-based assessment whereby the performance of an individual is related to others, regardless of what was taught and learned. In reality, things hardly changed, as teachers could continue tinkering with the same syllabi and familiar university-type tests, as long as they produced normal distributions of students across prescribed grade levels. A subsequent review in 1978 resulted in adherence to internal school examinations while norm-based assessment was replaced by competency-based assessment.

Following refinements over time, school-based criterion-referenced assessment coupled with external moderation by teacher panels is now established in Queensland. This dynamic system continues to develop, with new challenges ahead in view of the initiative for a national curriculum across Australia (Dudley and Luxton 2008).

Challenges to Science Education Within School-Based Assessment Policy

The changes in the Queensland assessment policy had to be accommodated by each school subject. Jim Butler (1995) reviewed the changes from the perspective of school science, with a focus on teacher development through participation in the implementation of criterion-based assessment. Teachers had to move from teaching for the test, based on a list of topics, past examinations, and predictions of what could be expected from this year's Chief Examiner, all the way to understanding, creating, and judging of standards, linking formative with summative assessment, and constructing student performance profiles. This process had not been fully completed when it was reviewed by Butler in 1995:

> The historical baggage of the past, the focus on students remembering content, and assessment determining the ranking of students rather than their level of achievement on stated objectives, is still somewhere within the science teachers. …. After fifteen years of operation, there is still room for development on the part of the teachers to completely understand and implement the vision. (pp. 152–153)

Has the abolition of external examinations changed classroom pedagogy? This was not studied systematically in science, but the available research shows that shifting practices is still difficult. For example, teacher concerns that nontraditional approaches disadvantage students at university were among the impediments to context-based curricula in senior classes. This was noted early in the implementation of newly required physics and chemistry syllabi (Beasley and Butler 2002), and again in the teaching of a later version (King et al. 2008). Clearly, university influences endure even when their domination through assessment is formally removed, but there are also obstacles to change within schools that are unrelated to secondary–tertiary interrelations, as had already been evident decades ago in the Eight-Year Study.

Despite flaws and not fully realized potential for fundamental pedagogical change inside classrooms, what has been achieved in Queensland's assessment system is unique. It was chosen as the model to follow in Paul Black's (2003) reflections on the history of assessment in England and Wales: "[I]n Queensland, all external assessments were abandoned… Can this country ever do this?" (p. 74).

Salters Courses: Sustaining Curriculum Innovation Within Changing Policy

The label "context-based" for curriculum and instruction is relatively new, yet it is linked to the Science-Technology-Society (STS) movement of the 1970s and can be thought of as a modified comeback of earlier versions of everyday life thematic teaching. Recent advocacy of the context-based approach features across Fensham's (2008) list of "emerging issues," from the way to meet the purpose of science and technology for citizenship that all students need, to the prospects of raising student interest, along with deeper understanding and transfer of learning: "Policy makers should consider mandating that science education should move progressively… towards a real world, 'context-based' approach to the teaching and learning of school science at all levels of the school curriculum" (Fensham 2008, p. 23). This recommendation is not fully substantiated by research (Bennett et al. 2007). Furthermore, realization is not easy, particularly so in advanced-level courses. Yet this is possible, even when external examinations are required, as exemplified through the Salters program in England that has been based at the University of York since its inception in 1983.

In the secondary science courses that carry the name Salters (after a cosponsor), being context-based is reflected in a structure that flows from contexts to concepts, with a series of contexts providing the spine around which concepts are revisited spirally. The many aspects of these courses, including development, implementation, teacher training and support, and the related research, were published in different phases of the program evolution and a retrospective comprehensive account was provided by Judith Bennett et al. (2005). I will highlight a few of the program's features along dimensions of change, starting with spread and institutionalization.

The Salters program began with a group of concerned chemistry teachers, academics, and industrialists who decided to make school chemistry more relevant in an attempt to raise student interest and increase course uptake. Their first products were application-led booklets for 13-year-olds that turned into a chemistry course, eventually spreading nationally to courses for older students and other subjects – initially advanced-level (A-level) chemistry, followed by physics and biology, with several overseas adaptations. Course materials are distributed through major publishers, and a specially designed external assessment is recognized by the regulatory body of England and Wales as comparable to veteran traditional courses. Spread is also evident in numbers, for example, Salters A-level chemistry students comprised 16.8% of the students taking A-level examinations in chemistry in 2008 (Christine Otter, personal communication, February 4, 2009). Scale-up occurred against a background of changing policies, starting with the revolutionary introduction of the National Curriculum in 1988. The influence of the National Curriculum extended beyond content constraints. For example, a shift of focus to "balanced science for all" during compulsory schooling led to the decision to embed the chemistry course within a new science course, otherwise "chemistry alone risked being marginalized from the mainstream" (Bennett et al. 2005, p. 124). Another example of policy effects is the need to adapt to modularization that allows students to split their A-level examination and acquire a stand-alone half A-level qualification. This meant that not only content, but sequence too, became a constraint that interrupted the gradual construction of concepts around a series of contexts: "Freedom of using STS content as organizer for the science concepts covered has eroded in the more recent courses" (Bennett et al. 2005, p. 127).

Has the Salters program brought a fundamental change? Encouraging evaluation results were reported (Bennett and Lubben 2006), but the match between original intentions and actual classroom practices, including regression over time, has not been fully explored. Apart from evaluation results, the answer to the question of fundamental change depends on interpretations of what is fundamental. Since all Salters courses explicitly care for science content, outcomes are unlikely to be appreciated as sufficiently radical by those who subscribe to the social reconstructionist conception of the curriculum (Jackson 1992). Educational researchers may argue that outcomes cannot be considered deep because the origins of the Salters approach are insufficiently theory-based, for example, in regard to a clear model of context (Gilbert 2006). While aware of shortcomings, I regard the cumulative achievements of the Salters program over almost 3 decades as fundamental, primarily since it broke away from the conventional structure of science courses and contributed to changing minds within the establishment: "[C]ontext-based (or contextualized) courses for mainstream secondary school science were seen as radical innovations. Today, the idea … has become almost an orthodoxy" (Millar 2005, p. 323). Almost an orthodoxy, and not everywhere, and as the history of education shows – unclear for how long.

Quality Teaching and Learning: The Challenge of Non-Tangible Pedagogical Change

The cases presented thus far are curriculum related; even the Eight-Year Study that had been initially defined as exploration and experimentation became largely concerned with curricular work. Educational reforms are often equated with new curricula, but while the term curriculum is broad, many projects tend to focus on its narrow sense of content specifications and tangible products, that is, curricular materials. Over more than 2 decades, the belief in salvation through resources has been also reflected in the form of ICT hardware. But resources are not directly linked to educational outcomes; they can only moderate the impact of instruction, as argued by David Cohen et al. (2003). This is a complex message, not easily grasped, as I realized in the role of participant-observer at the center for science education in Tel Aviv (HEMDA, Hebrew acronym) when I was its establishing director from 1988 to 2001 (Arzi 2007).

HEMDA was established at the initiative of a philanthropic foundation dedicated to education, with the grand goal of exemplifying quality instruction for quality learning in science through a new model of regional centers. Based on the belief in the advantages of the centralization and linkage of material with human resources, the center has its own facilities and teaching team, and its primary task is to serve as the common science campus for secondary schools in Tel Aviv. Right from the beginning, the specially designed building with clusters of laboratory classrooms became a showpiece. But there was considerably less interest in, and understanding of, the underlying educational rationale of quality teaching and learning in an environment that suggests and allows intertwinement of multiple practices (Arzi 1998; National Research Council 2006). Likewise, there was a general expectation for immediate proof that the investment paid off in terms of student grades in the external matriculation examinations, whereas unmeasured features of quality teaching and learning outcomes could be less easily marketed, though more difficult to achieve. In the following paragraphs I attend further to the perennial challenge of quality teaching for quality learning in a different context, through another long-term case that concludes my illustration of persisting issues.

The Project for Enhancing Effective Learning (PEEL) grew in Melbourne, Australia, from a classroom study with a biology teacher whose attempt to improve learning through enhanced metacognition was counteracted by the exposure of his students to traditional practices in other school subjects (Baird 1986). To reduce such unavoidable interferences, PEEL was designed as a cross-faculty action research with ten teachers in one school exploring classroom practices that would enhance their students' learning. Even so, it was not easy to achieve sustainable change in teacher and student behaviors (White and Mitchell 1994). Now there are PEEL groups in many schools in Australia and in other countries. Thus PEEL turned into a network of groups of teachers who share concerns about the quality of learning and interact in multiple modes, all under the leadership of Ian Mitchell from Monash University, who, in 1985, was the science teacher responsible for the start-up of the first group in his school.

A major instrument for intergroup interaction has been *PEEL Seeds* – a newsletter/magazine where teachers share their practices. In its 100th issue, Mitchell (2008) reflects back and looks to the future. Among his insights concerning the challenges of sustaining the process, he attends to the changing makeup of teacher groups due to new recruits joining in, making it necessary to meet different needs of teachers who are at different stages of PEEL-related development. In regard to the interrelations with the educational establishment in Australia, Mitchell (2008) notes that PEEL has not been embraced by policy makers: "[W]e were very difficult for the systems to deal with" (p. 16). At the same time, he observes policy statements gradually giving greater prominence to learning in ways that resemble the spirit of PEEL, although "they do convey a noticeably simpler view of what is meant by quality learning … and much less recognition of the complexities of achieving these changes in both teaching and learning" (p. 17). Apparently, change in policy rhetoric has not been sufficient, as is also evident in the review of science education in Australia by Russell Tytler (2007) who noted many teachers shifting their practices, alongside the resilience of traditional school science largely due to "the silent choice of teachers for the status quo" (p. 66).

Wrapping Up the Illustrative Cases

The first case of change through which I chose to illustrate target and process issues in science education attended to implications of a top-down assessment policy. The second case dealt with a university-based curriculum change. Teaching and learning were subsequently addressed through a brief acquaintance with a prototype center initiated by a foundation, and through a network of teacher groups that started with a single teacher who mobilized teachers and academics to embark on an adventure. Issues encountered in these contemporary cases can be identified in the Eight-Year Study – the lead case of this chapter that took place in the 1930s. A separate scholarly field of educational change emerged in the 1960s and has developed since then (e.g., Michael Fullan's (2007) book *The New Meaning of Educational Change* is already in its fourth edition). Still, obstacles to change that were present prior to its emergence continue to challenge us to date, and what is sometimes referred to as a theory of change may be a context-sensitive aggregate of conclusions of several programs with limited predictive value. I therefore concur with John Goodlad (2007) who believes that had the Eight-Year Study been replicated,

> … [w]e would find out pretty much what was found then. Policy makers would not pay much, if any, attention to it. And educational researchers and critics would have a great time arguing over methodology and implications. However, what we should do is examine the whole as a case study. (p. x)

Why Is Change Difficult, and How Do We Proceed?

Many reasons have been offered in the change literature as to why deep, sustainable, and widely spread change has been difficult to achieve (e.g., Fullan 2007; Sugrue 2008). Explanations, inter alia, point to fuzzy goals that are on the move either in response to socioeconomic factors or because of passing fads; politically driven policies having short time cycles; the web-like nonlinear nature of change processes; intended goals eroding due to involvement of multiple actors and interest groups; participant enthusiasm fading over time; resilient school cultures; preference for short- over long-term tasks; school principals not providing leadership; teachers who are under-qualified, or resist change, or both; and, insufficient funding for teacher training and long-term support. Some of these and other reasons were intertwined in the cases above; I will elaborate on one of them, referring to the dilemmatic and nested nature of persisting issues in science education.

Exemplifying Nested Dilemmas: Equity and Curriculum Differentiation

The current centrality of access and equity in science education is reflected in Fensham's (2008) list of issues for consideration by policy makers, where they are placed second only to the clarification of the purposes of science education. Fensham highlights the challenge of "getting the balance right" between the preparation of a scientifically based workforce and educating a scientifically literate citizenry, and recommends curriculum differentiation "at some stage in the secondary years" (2008, pp. 15–16). But curriculum differentiation is associated with tracking and contradicts the quest for equity; hence, this has been a controversial issue beyond the circles of science education (LeTendre et al. 2003). While it is encouraging to see successful detracking in a high school (Burris et al. 2008), it is important to listen to Nel Noddings (2007) questioning whether all students should take advanced academic courses and go to college. She insists that equality is not identical to sameness, and calls for a morally acceptable tracking that addresses different student aptitudes and interests.

Clearly, curriculum differentiation and equity entail dilemmas that extend beyond science education and have no consensual solutions. This is complicated further by the question of feasibility, since it is easier to offer parallel alternative courses in big rather than in small schools, yet small schools are thought to be more personalized and supportive. Thus, en route to achieving goals of school science we are confronted by dilemmas that cannot be managed solely within science education, as they are nested within schools, which, in turn, are nested within educational systems. Analysis of complex social phenomena go all the way from organizational subsystems to the societal level and the world system (Scott 2001); hence, a wide lens is necessary to understand and manage a particular change in science education with its wider interrelations.

From Incremental to Fundamental Change

The notion of many small steps rather than one revolutionary leap has been debated in the policy literature, unrelated to education, ever since Charles Lindblom (1959) advocated the idea of incrementalism, or “muddling through.” The likelihood for the accumulation of incremental educational changes into a fundamental change is questionable. At the same time, revolutions do not seem to occur frequently: “If you think about it, there has not been much to improve education since the invention of the printing press in the 15th century” (Joseph Novak, personal communication, December 30, 2003). Needless to say, setting Johan Gutenberg’s invention as the standard probably eliminates the chance of ever recognizing a change as fundamental. I see hope, however, in the phenomenon of hybrid pedagogies observed by Cuban (1993, 2009), as mentioned earlier in the case of the Eight-Year Study. The formation of stable hybrid pedagogies suggests that new ideas do enter the classroom door, and teachers know how to balance them with old practices that work. While it is possible to see these hybrids as indicators of failed attempts to fully transform the grammar of schooling, I prefer seeing the half-full glass: The grammar can be updated and rejuvenated; furthermore, change can be cumulative.

Change as a Permanent State

There are plenty of “how to do it” lists to guide successful change, some reflect conventional wisdom or experience of executives, some are also research-based. This chapter is not offering another list; rather, it aimed at cautious learning from past and contemporary attempts at change, acknowledging that despite persisting issues, and despite the gulf between reality and aspirations, good things have been happening. To sustain gains, reduce erosion, and move forward, efforts should continue:

> There is something pitifully juvenile in the idea that “evolution,” progress, means a definite sum of accomplishment which will forever stay done, and which by an exact amount lessens the amount still to be done, disposing once and for all of just so many perplexities and advancing us just so far on our road to a final stable and unperplexed goal. (Dewey 1922, p. 285)

I believe that large-scale programs – whether labeled top-down or assumed to combine top-down with bottom-up elements – will continue to meet modest success in reaching each and every classroom. They can, however, set examples and provide guidance, preferably research-based, for smaller-scale attempts. They should also empower teachers to do something different in a single lesson in a single classroom, and to be continuously involved in improvement and renewal, either self-initiated or in response to external stimuli. A local initiative that brings about a fundamental and sustainable pedagogical change, yet does not seem to scale up, has value, particularly if many initiatives are happening and a critical mass is gradually accumulated. While aware that schools and teachers need stability, the main message is that to rejuvenate and enhance science education continuously, change is a desired permanent state that should become the norm.

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Chapter 60
Globalisation and Science Education: Global Information Culture, Post-colonialism and Sustainability

Lyn Carter

Introduction

It is increasingly clear that contemporary education, including science education, needs to be considered in tandem with globalisation[1] as the dominant logic at work, rethinking and reconfiguring the social landscape in which education is embedded. Globalisation refers to the recent transformations of information, capital, labour, markets, communications, technological innovations and ideas stretching out across the globe that have become fundamental for constructing our understandings of the contemporary world. The everyday consciousness is now one of a global imaginary, making us feel connected to far-flung places and events. Gerald Delanty (2000) is amongst the many theorists who broadly group the various characterisations of globalisation into political economic transformations and socio-cultural changes. Within the former, the processes of convergence foster an increasingly hegemonic homogenisation embodied in the growth of market ideologies and of supra national regulation, the extension of the enterprise form to scientific and technological innovation, and the expansion of Western capitalism and culture. Socio-cultural characterisations on the other hand, emphasise the divergence in local adaptations of larger global forces so that diversity, identity and fragmentation become the leitmotifs of the global age. Globalisation can be thought of as a complex dialectic of both political-economic and socio-cultural transformations that are still to be fully configured even as they work themselves into the materiality of the

[1] I use Australian colloquial spelling throughout the paper, including the spelling of globalisation with an 's' rather than a 'z', as indicative of "the local adaptations of larger global forces so that diversity, identity and fragmentation become the leitmotifs of the global age".

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everyday. Education (read science education) and globalisation thus become mutually implicative categories where globalisation acts as the macro-level sets of forces shaping the conditions for and being expressed within education, and education circulates globalisation.

As the most macro of all of the discourses, globalisation draws from many disciplines and perspectives in an attempt to make sense of the complexities of contemporaneity. One such example is the work of Scott Lash (1999, 2002) and Scott Lash and Celia Lury (2007) who focus on global information culture because they believe it better emphasises the unifying principle of globalisation's architecture, that is, information itself. By information, Lash (2002) means not only the knowledge-enriched goods and processes that are the stock and trade of new global markets, but also the more recent form of information as cultural object, that is, information as superseded message. Small, message-sized bites of information like the latest stock market figures, the newest celebrity scandal, the most recent sport score, the hottest trend, the most topical political story and so on, incessantly circulate the globe constantly being updated and made obsolete. In contrast to the long-tested wisdom base held in the discursive structures of industrial society, informational knowledge comes to possess a limited currency and we become swamped in information overload, misinformation, disinformation and out-of-control information. Hence Lash (2002) argues, in global information culture the symbolic power resides with intellectual property that gets compressed and is quickly replaced leaving almost no time for reflection. Clearly Lash's (2002) views hold profound implications for contemporary education whose raison d'être and currency is knowledge be it regarded as information or otherwise.

At the same time as theorisations of globalisation like Lash's find purchase, there has been a growing acceptance of the ecologically fragile state of our world and the probability of looming crisis. While scant attention was paid to the declaration of the Union of Concerned Scientists (1992) starkly titled *World Scientists' Warning to Humanity*, the increasing realities of climate change mean that sustainability discourses have now become global in their reach. The declaration concluded:

> … [I]f not checked, many of our current practices put at serious risk the future that we wish for human society and the plant and animal kingdoms, and may so alter the living world that it will be unable to sustain life in the manner that we know. Fundamental changes are urgent if we wish to avoid the collision our present course will bring about. (Para 1)

The links between limits to growth and hyper-consumption levels enabled by fossil fuel use, consequent to what Clive Hamilton (2003) calls growth fetishism, means that human activities have fundamentally altered the conditions for life. These include changed weather patterns, the reduction of the ozone layer, desertification and degradation of agricultural land, the depletion of forests, loss of biodiversity and species habitat and the pollution of the atmosphere, waterways and oceans. The key issue has become for many, including some science educators, the complex question of how best to effect the transition towards a sustainable future.

Considering global sustainability issues highlights the impacts of the minority world upon the majority world or the Global South[2] where the latter's resources are used for the benefit of the former, and where devastating environmental effects are experienced more acutely. The discourses and activities of post-colonialism have been useful in describing trans-cultural processes, including global knowledge production and environmental issues, and critically appraising their effects. Graham Huggan (2001) sees post-colonialism as offering at the same time political analysis, cultural critique, and philosophical insight so as we can work simultaneously from all these positions to acknowledge the realities of historical and contemporary circumstances. This interdisciplinary approach enables, suggests Alfred J. Lopez (2001) paraphrasing Foucault, a condition of multiple criticisms not reducible to a single position, yet efficacious in their interrogation of a range of practices, institutions and discourses that enhances its power as oppositional thinking. Post-colonialism is thus able to critique contemporary global cultural processes unevenly restructuring the world, identify neo-colonialism as part of globalisation, and help us work towards new political and intellectual interventions in the cause of redistributive justice.

Clearly, there is a need for science education to inquire into the complexities of contemporaneity, be they expressed as global information culture, post-colonialism, the transition to sustainability, or any one of a number of other discourses of globalisation, so as it can engage in dialogues about key issues that are practically and intellectually urgent, and which must be addressed if science education is to remain relevant. In this chapter then, I describe the three discourses of global information culture, sustainability and post-colonialism as aspects of the macro-discourse of globalisation, to enable science education to reposition its directions so as contemporary challenges can be better addressed. I have already suggested elsewhere that despite science education's preference for the traditional types of analyses, globalisation is clearly at work in science education's more recent policy and practical transformations (see Carter 2005a, 2008a). Here, I extend this discussion and outline these three global discourses before moving on to identifying some of their implications which we as science educators can only begin to grapple.

[2] The appropriateness of terms used to describe contemporary asymmetrical economic political and social world relations (or indeed, globalisation) is much debated within the literature. For example, the *First* and *Third Worlds*, *developed* and *developing* nations, *minority* and *majority* worlds, the *West*, *East* and *Middle East* (which only make sense if one is situated in Europe or America – from places like Australasia, America is to the East!), are all imbued with the semiotics of historical power and coloniality. Here, I adopt the use of *Global South* which encodes a colonial past and continuing disadvantage within the hegemony of globalisation, and *Global North*, which Sandra Harding (2006) refers to the origins and beneficiaries of the dominant knowledges, criteria, choices and actions including those of contemporary globalisation and global information culture. The *Global South* and *North* have both geographical and metaphorical immanence, but as Walter Mignolo's (2007) binaries show, diaspora sees the *South* as part of the geographic *North*, and the imposition of various imperialisms mean that the *North* is part of the *South*.

Global Information Culture

The complexity of our times argues Lash (1999) is characterised by a shift from a national industrial society with its accumulation of goods and capital, and its social and civil institutions and norms, to a global information order where informational processes dominate, and individualisation is the new norm of social life. It is the age "of the inhuman, the post-human and the non-human, of biotechnology and nanotechnology" (p. 12), of an object material culture in which technologies, objects of consumption, lifestyles and so forth come to dominate the cultural landscape. Material goods are informationalised with their knowledge-intensive designs, regulated content, global reach, inbuilt obsolescence, and their branding and trademarking that can confer an instant recognition and worth often beyond the utility of the object. The intellectual value of relentless innovation disembeds objects from real value producing within the developed world, a knowledge-intensive rather than work-intensive society with design studios and R&D laboratories replacing the factories and their environmental consequences that have moved into the Global South. For Lash (2002), these non-linear, socio-cultural-technical assemblages that produce flexible, mobile, value-added and issue-oriented processes and artefacts as need dictates, are highly differentiated in terms of access and control. The consequences include a networked global elite that identifies more with itself than with others, and an underclass excluded from the informational structures and flow. As low-skill labour becomes more and more irrelevant to knowledge accumulation, power is manifest in a new form of exclusion and inclusion that Lash (2002) argues is inherently more socially and environmentally violent and devastating.

Integral to Lash's (2002) global information order is the theory of unintended consequences. The flip side of knowledge-intensive processes and artefacts argues Lash (2002), is a ubiquitous overload of information that flows and circulates, overwhelms and consumes as it spins out of control. This is disinformation, that is, information compressed to the immediacy of the present, message-sized, fact-based rather than abstract, instantaneously relevant, and whose speed and ephemerality prevents our engagement because there is just too much to which we can pay attention. In the swirl of these information flows, brand names, trademarks, platforms, regulations and standards become fixed reference points that help ameliorate the otherwise anarchy of overload. Without the time to develop narrative and discursive structures, deep meaning disappears leaving only the application of algorithms that seem as if they at least sometimes work! For Lash (2002), the rationality of knowledge-intense production has resulted in out-of-control information, causing a chronic dialectic of disordering, reordering and disordering again that he suggests, threatens to dumb us all down as we swirl around within its flow.

Like many other globalisation theorists, Lash (2002) does not discuss education at length. However, he does suggest that knowledge-intensive production requires an education that reflects the highly analytical nature of that knowledge. Such knowledge is discursive, based upon abstraction, selection, and complexity reduction, and emphasises highly codified mathematical, verbal and computing skills.

It problematises and tests out concepts, applies systematic rules, subsumes particulars, looks for connections, and attempts to be reflexively aware of all possibilities. It contrast to the hands-on, practical knowledge of manufacturing society, this education emphasises the production of abstract outcomes like rationally argued essays or research papers that elevates knowledge production as intellectual property.

Yet, there is a rub. Robert Reich (1991) has identified the 'symbolic-analytic', 'routine-production services' and 'in-person services' as three emergent categories of work in this new knowledge order. Symbolic-analytical workers are relatively small in number, stable in identity and proportion, and are involved in knowledge-intensive production and services. They are the networked global elites. But with the material demands of an embodied life still with us, and the consequent outsourcing of most aspects of living from cleaning to child care, Reich (1991) argues that the greatest job expansion is really in lower knowledge and skill categories of routine-production services and in-person services.

Reich's (1991) categories when connected to a discursive education that is fundamental to Lash's (2002) global information culture raises important questions about the real purposes and distribution of a discursive education that is the current form of science education. Discursive education radically intensifies the narrow form of knowledge prevailing in science education since the massive reform efforts of the 1960s that privileged abstract knowledge and was explicitly geared to train future scientists and engineers. This approach was, and remains, in tension with a more general education required by the diverse learners staying on longer at school. The broadening of science education that occurred in response to the failure of these reforms (see amongst many other scholars Howard Gardiner [1999] for a discussion of broadening learning styles, and Glen Aikenhead and Olugbemiro Jegede [1999] for more diverse cultural approaches to science education) comes to be increasingly under threat. A reinvigorated narrowing of science education to highly codified knowledge in the interests of successful knowledge production as intellectual property brings with it an emerging constellation of power and inequality issues that we can only just begin to grasp. When coupled to Reich's (1991) description of the relatively small number and proportion of symbolic-analytic workers, or global elites, supported by the global information economy, it is clear that such an education is suitable for only a very few. Those that succeed with discursive knowledge not only have access to the more secure, higher paid specialized jobs, but are also able to better negotiate their way through the complexities of global information society.

Difficult as these issues are, perhaps the most challenging aspects of contemporaneity to which all education, including science education, must respond is Lash's (2002) flip side, that is, his description of the disinformation society with its speed and ephemerality and its chaos of information overload. Flows solidify into standards, regulations and platforms of mantra-like rhetoric, brands names and trademarks that can only be temporary even if they appear otherwise. If nothing else, Lash's (2002) view of information flow gives us a perspective on the development of educational standards as part of the existence of other types of standards, regulations and platforms that attempt to fix reference points and impose some order upon the overwhelming informational chaos. In this view, educational standards are constructed as virtual objects able to circulate around the world, taking on a discursive meaning and importance beyond themselves and becoming representational of all types of actions and relationships. It is only when points can be set despite their inbuilt obsolescence that they can be utilised within neoliberal markets as products of exchange or commodities of comparison. The PISA tests spring to mind here. Moreover, the rise of neo-conservatism's attempts to influence such standards with what is already known and valued, is eminently understandable in a space of the vast speed of disinformation and its flows.

So, in what ways then, can science education enframe disinformation to help make sense out of the anarchy of such flows? In the sea of information, to what should science education pay attention, and for what purpose? How do we make science education more equitable, inclusive and relevant to all learners? How do we help our students develop skills, discursive or otherwise, for this complex new world? Such questions are only just becoming apparent and articulated as crucial to formulating a twenty-first-century approach to science education. Generating possible answers is another matter, and the danger is that our strategies will have too much of a past flavour as we are likely to start from the restricted social and cultural forms Peter McLaren and Gustavo E. Fischman (1998) see as still gripping much educational debate including our own within science education. This danger is apparent in our literature with its under-theorised view of contemporaneity and under-examined assumptions, polemic even, about increases in student interest, motivation and learning destined to flow from our business as usual approach to pedagogy and curricula.

Sustainability

Turning now to the second globalisation discourse, it is clear that the recent increasing awareness of issues of sustainability responds to the growing acceptance of the ecologically fragile state of our world with its vast human load beginning to exceed carrying capacity. Sustainability issues are identified in a large number of international reports and meetings including; the Conference on Environment and Development (United Nations General Assembly 1992) that developed the blueprint for the global implementation of sustainable development: Agenda 21: Our Common Journey (National Research Council 1999); United Nations Millennium Declaration (United Nations General Assembly 2000); the United Nations World Summit on Sustainable Development (2002) held in Johannesburg; and the collaboration of the International Council for Science (2002), Science and Technology for Sustainable Development. More recently we have seen the highly influential Intergovernmental Panel on Climate Change's (IPCC; 2007) Climate Change 2007 and The Economics of Climate Change, The Stern Review (Stern 2007) and locally the Garnaut Climate Change Review conducted in Australia by Ross Garnaut (2008).

As a conceptual field, sustainability owes much to disciplines including anthropology, geography, all branches of science but especially environmental science, technology, peace and development studies, economics, social and political sciences, globalisation, cultural studies and so on. Indeed, Robert Kates and the 2001 Swedish Friibergh Manor Workshop identified sustainability as a trans-disciplinary field that recognises the limitations of traditional science and other disciplines in investigating the complexities of socio-ecological assemblages (Kates et al. 2001). Building upon the Friibergh Statement, William Clark and Nancy Dickson (2003) and Robert Kates and Thomas Parris (2003) are amongst those who have argued for a more systematic and international consensus on the priorities, goals and assessment mechanisms facilitating the transition to sustainability.

Most of these documents and meetings endorse the belief that at the heart of the transition to sustainability is the need for a deep paradigm shift in humanity's collective cultural values:

> What is needed is a fundamental transformation of people's attitudes and practices. … Only a new world view and morality can change the basic relation of people to the earth. People's behaviour is a matter of choice based upon values. … The need for a world ethic of sustainability – an ethic that helps people cooperate with one another and nature for the survival and well-being of all individuals and the biosphere – could not be greater. (Amy Cutter 2001, p. 2)

While individual and collective efforts to reduce resource consumption and conserve biodiversity are to be commended, it is the deeper levels of cultural values and identity that must be ultimately addressed to enable any real progress to a sustainable future. Over the past 200 years the very ideas of progress, success and civilisation, especially in the Global North, have arisen from humanity's ability and willingness to use the earth's resources for its own ends. A profound change of culture is required to reshape human relationships with the natural systems of which it is part and on which it depends.

It is also widely accepted that education is one of the most effective means we have of bringing about such a change. Annette Gough (2008) tells us that the field that was to become environmental education arose out of the growing awareness of environmental degradation first identified in Rachel Carson's (1962) book *Silent Spring*. The development of environmental education throughout the 1970s emphasised an environmental knowledge base that privileged the natural subsystems and reduced biophysical human interactions to a series of inputs or outcomes (Alan Reid and William Scott 2006). Over time, this conservative apolitical and scientific approach underwent a substantial shift towards the promotion of sustainability and sustainable development as its inadequacy for understanding the dynamics and complexities of nature–society became apparent. Initially endorsed by the World Conservation Strategy (International Union for Conservation of Nature 1980), and later by the 1987 Brundtland Report (Brundtland 1987), education for sustainability (EfS) calls for the development of a conservation mindset within environmentally sound values and the sustainable use of natural resources. It placed humans into the system recognising all the messiness that socio-ecological assemblages entail. This new agenda was firmly embraced by the United Nations General Assembly (1992) earth summit conference on environment and development, Agenda 21. Indeed, the highly influential Agenda 21 emphasised the role of education as an agent of sustainability.

> Education is critical for promoting sustainable development and improving the capacity of the people to address environment and development issues. … It is critical for achieving environmental and ethical awareness, values and attitudes, skills and behaviour consistent with sustainable development and for effective public participation in decision-making. (Chapter 36, Para 36.3)

In an excellent overview, Gough (2008) describes the lengthy relationship between science education and the earlier manifestation of education about and for the environment as environmental education, and in its more recent form of EfS. In essence, she suggests that the relationship between environmental education and science education has strengthened, with a growing recognition that an understanding of ecological sustainability is essential if we are to achieve a sustainable future. Gough (2008) believes that EfS should be part of any approach to science education that maybe reconceptualised in an attempt to address the decline of student interest in school science apparent from many studies by those like John Dekkers and John de Laeter (2001), and perhaps most significantly, the extensive Relevance of Science Education (ROSE) Project (for details see Camilla Schreiner and Svein Sjøberg 2004). ROSE has found that students across the developed world are largely disengaged from science education finding it boring and irrelevant to their needs, while those from the Global South see it as a passport to prosperity. This is, of course, not surprising when placed in the context of Lash's (2002) global information culture that speaks to the relentless global circulation and consumption of informationalised, technologised and taken-for-granted products and processes in which today's affluent youth are embedded. It also speaks to the desire of many from the majority world to become part of Reich's (1991) symbolic-analytic workers discussed above.

Gough (2008) quotes Edgar Jenkins and Godfrey Pell (2006) to conclude that since many environmental problems (and their solutions) are science related, there is clearly a role for school science education, and goes onto argue that

> [b]y bringing science education and environmental education together in the school curriculum, science content is appropriate to a wider range of students and more culturally and socially relevant. The convergence is also important for environmental education, because it needs science education to underpin the achievement of its objectives and to provide it with a legitimate space in the curriculum to meet its goals. (p. 41)

What then constitutes good EfS that can contribute towards science education? The literature suggests that there are a number of characteristics that EfS clearly exhibits:

- Concerned with how people interact with their total environment and with addressing environmental problems holistically through the curriculum. Hence, holism is its philosophical basis.
- Employs synthesis as a methodological approach which assumes that studying interdependence and interactions leads to the emergence of new properties.

- Investigates the environment at different environmental scales. This means investigations of different local, regional, national and global environmental problems and an exploration of their links.
- Recognises that engagement in environmental improvement extends beyond the cognitive to an individual sense of responsibility generated by a personal environmental ethic. Thus, central to the success of EfS is the promotion of an environmental ethic which has sustainable living at its core.

Hence, EfS tends to involve issue-based learning with students considering relevant knowledge content and concepts, values and morality. Typically, students engage in the processes of (1) identifying issues, (2) investigating issues, (3) seeking solutions to issues, (4) carrying out actions to address issue, and (5) evaluating the impact of the environmental actions taken to resolve these issues. It is not merely about discussing solutions in order to enhance awareness; rather, it is purposeful and active exploration of issues, and the identification and enacting of potential solutions. Science education lends itself well to such an approach, and in partnership with EfS, can work to re-engage young people and help empower them as globally responsive and environmentally sustainable future citizens.

Post-colonialism

And so to the final global discourse under discussion here, that of post-colonialism. With its origins in Commonwealth literatures, literary and cultural studies, and social theory, post-colonialism is a heterogeneous field that stretches across different historical periods, cultural activities and geographical regions. It draws from, in disciplinary terms, cultural studies, anthropology, international relations, economics, history, politics, and literary studies, resourced by the critical practices of post-structuralism, feminism, Marxism, psychoanalysis and linguistics. For Robert Young (2003) and others, it is an elastic and highly contested notion that simultaneously includes, firstly, post-colonialism as epoch that acknowledges post-World War II international decolonisation, not only commemorating resistance over colonial powers but also describing post-colonality as the contemporary condition of existence. Secondly, post-colonialism describes the development of new aesthetic and cultural formations responding to these changed historical circumstances. Post-colonial cultural producers rework the historical ruins of colonial relations to foreground the complexities and hybridities of human social and cultural realities. Thirdly, post-colonialism as methodology draws from post-structuralism and deconstruction as the theoretical method of postmodernism. In this vein, earlier Fanonian-inspired and Marxist projects of resistance and their attempts at historical recovery have given way to the more post-structurally driven theorisations of identity, difference, hybridity and ambivalence prominent in the work of those like Homi Bhabha (1994) and Arjun Appadurai (1996). Lastly, post-colonialism refers to an ethical and political project resisting hegemonic power and seeking redistributive justice at the local and everyday levels as sites of intervention and renewed action.

Despite post-colonialism's broad but essential heterogeneity, many theorists have suggested significant clusters of ideas useful for considering the post-colonial. These ideas, while differing in scope and emphasis, inevitably include the constructs of cultural translation and representation, difference, multiculturalism, hybridity, localism, boundaries and borders, fragmentation, and pluralism in ways that reshape the categories of culture, identity and difference. Post-colonial analysis usually proceeds around a critique of embedded binary representations of the Other, the hegemony of some forms of knowledge and delegitimation of others, the spread of modernity with its liberal humanist rhetoric of universalism, the role of the economic-political, as well as developing capacity for Third World agency.

One way in which post-colonialism proceeds in its project is as deconstructive or oppositional reading practice in the post-structural tradition that draws attention to the unconscious in textual practice. For Deborah Britzman (1995), the unconsciousness of texts not only operates at the level of the cultural unconscious as types of coordinates of thought, but also at the level of what cannot be said precisely because of what is said. Deconstruction is interested in what is not said, and in what is repressed or concealed, and must be detoured around in order for a text to develop its sense of completeness. Ian Stronach and Maggie MacLure (1997) believe these absences and elisions are generally ideologically motivated and 'that to read against the grain – to interrogate texts for what they fail to a say, but cannot fully cover up – is to reassert the existence of a plurality of voices, values and perspectives' (p. 53). Similarly, Britzman (1998) believes 'reading practices might be educated' (p. 85) and draws on Shoshana Felman's (1987) analytic practices of interpretation as processes to privilege reading practice over the intentions of the author, and so disrupt inside/outside hierarchies and unsettle the sediments of imagined normalcy. This would expose, she suggests, the refusal of difference masked under liberal humanist practices of inclusion and empathy that in their acceptance of Otherness really means a legitimation of processes of Othering. Consequently, post-colonial reading and (re)reading (after Cleo Cherryholmes 1999, 1993) practices can interrogate texts and uncover the unconscious (neo)colonial thinking that can paradoxically lurk behind overt anti-colonial author sentiment, and provide alternative analyses from those that are expected. Such counter-readings attune us to the long-standing colonial practices and assumptions deeply sedimented into normative scholarship and emphasise the need for vigilance in order to recover critical spaces for oppositional thinking and practice.

Ato Quayson (2000) argues that all these forms of post-colonial critique should be important to many domains of knowledge as part of a larger project interested in differential experiences and social redress. As much of science education's scholarship articulates an interest in such concerns, it follows that post-colonial theory should be indispensable to science education.

To date, science education has been reticent to engage with powerful discourses like post-colonialism. Some prominent exceptions include Noel Gough (2003), Elisabeth McKinley (2001) and Peter Ninnes (2001). This seems like an oversight because, as already noted, post-colonial perspectives can offer science education at once political analysis, cultural critique and philosophical insight to disrupt the continuing Eurocentrism of comparison and multiculturalism with their philosophical and epistemological assumptions of universalism, difference and the Other. These assumptions are bound to stable and unitary ideas of nation, culture, identity, comparison and difference which, though now outdated, remain embedded within much of science education's traditional discourse on multicultural education and cultural diversity that has been deployed to address the eruption of difference under globalisation. Post-colonial perspectives can help science education develop more appropriate and complex conceptualisations that include cultural translation and representation, difference, hybridity, localism, boundaries and borders, fragmentation, and pluralism in ways that reshape the categories of culture, identity, and difference better suited to contemporary transnational global culture. They can also expose some of the new forms of imperialism being entrenched within globalised approaches to science education reform. For Jay Lemke (2001) and others like Bill Kyle (2001), these areas remain under-acknowledged and under-theorised within science education's scholarship.

More specifically, post-colonialism as one of its approaches, can offer science education the unique methodological insights that come from deconstructive or oppositional reading practice, which while prominent elsewhere have yet to be explored within science education. As indicated above it can draw attention to the unconsciousness in textual practice that despite author intentions can articulate meanings constituted, recited and circulated through long-standing and hegemonic practices. Indeed, some of my own scholarship in the tradition of Cherryholmes has attempted to re-read several of science education's published texts from a post-colonial perspective and reveal lingering colonial referents different from what we thought were present. Such tasks are only just beginning to be thought about and most of this work is still to be done, as it is profoundly challenging. Nonetheless, the significance of post-colonialism for science education lies in its willingness to look beyond science education's conventional categories of analyses, and to help revise its philosophical frameworks in the face of an overwhelming, uncertain and rapidly reconfiguring world (see Carter 2004, 2005b, 2006, 2008b).

The Discourses of Globalisation and Science Education

The discourses of globalisation outlined here remind us that we are indeed living in a challenging world. One example of the implications for science education can be seen with Masakata Ogawa's (2001) description of the decreasing desire of Japanese youth to be involved with science despite a very high receptivity to techno-scientific products and services. Ogawa (2001) quotes the Japanese sociologist Kobayashi in arguing the inevitability of such disinterest in advanced techno-scientific informational society. These observations speak to the Lash's relentless global circulation and superficial consumption of informationalised, technologised and taken-for-granted products and processes in which today's affluent youth are embedded. At the same time though, other research tells us that many young people are becoming actively involved with health of the planet as well as social justice and redress for the excluded and powerless. What happens, then, in terms of student interest and knowledge if these global socio-cultural and political contexts of science are taken into account? Such questions are important because they scrutinise assumptions about students' motivation to engage in science education of whatever persuasion, particularly now as young people well versed in dis/informational knowledge and flow may need to be convinced that any science education is worthy of their time and attention.

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Chapter 61
Metaphor and Theory for Scale-up Research: Eagles in the Anacostia and Activity Systems

Sharon J. Lynch

As a researcher studying the scale-up of science curriculum units in middle schools, I was startled awake early one morning (c. 2004) when I heard the word 'scale-up' issuing from the National Public Radio news on the clock radio. In an interview about a worrisome impending winter flu epidemic and vaccine shortages, a reporter and a pharmaceutical researcher discussed the need to *scale up* vaccine production. Not only was much *more* of the stuff needed, but the industry also had to find *better ways* to produce it in quantities that could meet the rising demand from a concerned public. Another problem was *how to distribute* the vaccine to those who needed it most. Fully alert, I pondered the application of flu vaccine scale-up metaphor to issues facing my research team in studying the scale-up of science units with a partner school district. Our studies were designed to determine the interventions' effectiveness at small scale, and explore if they could be taken to large scale without diluting their impact on student learning. As with the flu virus, both 'production scale' and 'distribution' of the curriculum units were mettlesome problems.

The field struggles to define, describe and understand the scale-up of interventions in education. The ultimate goal is to improve education by stimulating large-scale adoptions of interventions having strong evidence of effectiveness. My research programme was stimulated by funding from the Interagency Educational Research Initiative (IERI) whose goal is to 'increase the knowledge of *scaling up* by supporting research that investigates the effectiveness of educational interventions …[and]…requires …understanding of the learning outcomes related to specific educational interventions with a rigorous analysis of the logistical, organizational, political, and economic factors that facilitate or impede [scale-up]' (National Science Foundation 2002, p. i). IERI funded 101 educational research projects, about evenly distributed among reading, science and mathematics.

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The study of scale-up in education has been relatively untrammelled territory and is admittedly under-theorised (Coburn 2003; McDonald et al. 2006). In the fall of 2003, a group of IERI researchers and theorists met to discuss scale-up of educational interventions. Experts from fields outside education described scale-up from perspectives such as economics, technology, computer science, sociology, engineering, statistics, psychology and organisational behaviour. By exploring analogues in other disciplines, educational researchers perhaps would develop theories to explain the scale-up of interventions in school systems (cf. Schneider and McDonald 2007a, b).

Theorising Scale-up/Scale-up Research

Normative Dimensions for Outcomes of Scale-up

At the same time when the IERI conference was taking place, Cynthia Coburn (2003) framed her views on scale-up by developing criteria to guide the study of scale-up of whole-school reform interventions. She suggested that traditional definitions of scale-up (the deliberate expansion to many settings of an externally developed school restructuring design that has previously been used successfully in one or a small number of school settings) are too limiting and would not capture the normative aspects of scale-up in education settings. Coburn reconceptualised scale-up outcomes to include four interrelated dimensions:

- *Depth* (the reform must affect a deep and lasting change in classroom practice)
- *Sustainability* (it must last within the school or school district or continue to scale, even after start-up funding has run out)
- *Spread* (the intervention must include not only the spread of activity structures, materials and classroom organisation, but also spread of underlying beliefs, norms and principles to additional classrooms and schools)
- *Shift in reform ownership* (the reform is no longer external to the school and controlled by the reformer, but internal with the shift of authority and knowledge to teachers, schools and districts)

Coburn focused on scale-up from the standpoint of programmatic or normative outcomes of scale-up for schools or larger education entities. Her policy perspective applied to school systems, but was stimulated by her in-depth case study of a single elementary school that had participated in the Child Development Project (CDP), a whole-school reform programme for elementary schools. Coburn's study occurred the year *after* outside funding had ended and focused on CDP's ability to stick in this school after CDP researchers had withdrawn. She suggested that that scale-up theory ought to be about more than just numbers; it should also attend to the four dimensions listed above. Given the substantial human effort and financial costs of whole-school reform efforts, questions of 'worth' arise. Coburn's four normative dimensions for scale-up might be interpreted as criteria for determining the value of a scaled-up intervention over the long term, raising non-trivial questions about interventions intended for scale-up and their costs, consequences and long-term worth.

Scaling-up Exemplary Interventions

Sarah Kay McDonald and other members of the Data Research and Development Center (DRDC) at the University of Chicago provide a different view of scale-up research and theory based upon their unique position as a knowledge-building group charged with the management and dissemination of results from the IERI scale-up research portfolio (McDonald et al. 2006). McDonald et al. theorise about scale-up from the frame of university researchers focused on the knowledge that emerged from the IERI research portfolio, rather than that of researchers who worked directly with schools participating in such projects. McDonald et al.'s view is that scale-up research is primarily about numbers – valid and reliable data from studies constructed to be generalisable to increasingly large and varied contexts. They define scale-up as the practice of introducing proven interventions to new settings with the goal of producing similarly positive effects in larger, more diverse populations. Scale-up research examines factors that influence the effectiveness of interventions as they are brought to scale across settings. McDonald et al. partition scale-up and, correspondingly, scale-up research, into three stages. The goal of the first stage is to demonstrate that an intervention is *effective* and leads to improvements for students in a given set of circumstances. In the second stage, the goal is to determine if the intervention is *scalable*, spreading to more sites with varied contexts while maintaining its success. The third stage involves the ongoing evaluation of implementations (i.e. the intervention's s*ustainability and efficacy* across sites and over time). Scale-up research focuses on contextual factors necessary for success as an intervention scales. In contrast to Coburn, these authors believe that scale-up is inherently about size, numbers and doing more and about 'extending the reach of an exemplary intervention to produce similarly positive effects in different settings to reach a greater number of students, teachers and setting' (McDonald et al. 2006, p. 16). Research trials and comparisons allow generalisations about how and when to use the intervention in different contexts.

Although McDonald et al. and Coburn approach scale-up in different ways, both contribute to theory building. The intention for this chapter is provide a third perspective on scale-up theory which arises from participation in a 6-year research programme on the scaling-up of middle school science curriculum units in a large and diverse public school system. The name of this research programme is Scaling-up Curriculum for Achievement Learning and Equity Project (scale-up).

Scale-up in Context: Science Curriculum Units

An Overview of Scale-up

Sharon Lynch, Joel Kuipers, Curtis Pyke and Michael Szesze (2005) designed scale-up to study the systematic scale-up of three reform-based science curriculum units in middle school classrooms in Montgomery County Public Schools (MCPS), Maryland. MCPS is the 14th largest school district in the USA and one of the most diverse. Scale-up was completed in 2007 after reaching 6th and 8th graders in about 35 middle schools and 7th graders in 10 schools, including about 250,000 students and over 120 science teachers. Scale-up involved three different middle school science curriculum units of limited duration (3–10 weeks) that were created by three different research-oriented institutions. Each of the units has well-defined instructional characteristics that are thought to be important for student learning according to criteria developed by Sophia Kesidou and Jo Ellen Roseman and their working group at Project 2061 (2002). Although each unit had been field-tested prior to scale-up, none had been studied using a rigorous quasi-experimental methodology, combined with an extensive ethnographic component. Consequently, the effectiveness of each unit was an open question, as was how it functioned in classrooms (Lynch et al. 2007a).

Each unit focused on a different challenging science target idea (conservation of matter, reasons for the seasons, and motion and force) that research shows as challenging for children (and adults) to understand (cf AAAS 1993). The dependent variables for each unit studied were student outcomes scores on curriculum-independent assessments. Classrooms of students from five pairs of carefully matched schools were randomly assigned to a treatment or comparison condition for each science curriculum unit. The resulting samples mirrored the middle school population. Each unit was studied in this way for at least 2 consecutive years (Lynch 2008). If an intervention curriculum unit was effective both overall and when data were disaggregated (by ethnicity, or eligibility for Free and Reduced Meal Status (FARMS), English for Speakers of Other Languages (ESOL), or special education services), then it would be considered for scale-up to 35 middle schools in the district. Scale-up would also study how the unit functioned in a classroom from an ethnographic perspective (Kuipers et al. in press) and explore additional factors of ‘school experience’, ‘outcomes at large versus small scale’ (Watson et al. 2007) and ‘fidelity of implementation’ (Lynch 2008; O’Donnell et al. 2007).

Pragmatics of Scale-up Research

Equity issues were paramount to scale-up’s curriculum effectiveness studies. The intervention curriculum units had certain instructional strategies, congruent with Project 2061’s Curriculum Analysis (Kesidou and Roseman 2002). These units seemed more likely to be more effective than the business-as-usual curriculum materials in use in the district, such as traditional science textbooks, other reform-based curriculum materials, Internet and video resources, and district-constructed curriculum guides. Scale-up would test the effectiveness of each intervention units both overall and when student outcome data were disaggregated by ethnicity or eligibility for FARMS, ESOL or special education services (Lynch 2000). If some subgroups of students were disadvantaged by an intervention unit, then certainly the decision to scale it up would be problematic. However, if a unit was more effective overall and passed the equity litmus test, then the goal was to study its movement to scale in the school district, exploring its potential for closing achievement gaps in the long term.

Scale-up was dependent upon four conditions for research collaboration that emerged prior to, or very early on in, the endeavour: (1) close partnership between researchers and school district educators; (2) recognition that the success of any intervention is determined by the pervasive policy climate of the powerful school system; (3) quality of assessment feedback and other information that both permit and drive scale-up decisions; and (4) well-organised research agenda to systematically introduce new curriculum units to teachers. The scale-up of the units was unlikely to occur, as past experiences in the partner school district had already shown (Lynch et al. 2007a), unless each condition was addressed as discussed in detail below.

Close Partnership Between Collaborators

At the outset, the scale-up university researchers and school district science coordinators and evaluators had to establish common goals for the study. Scale-up was viewed initially by school district leaders as a long-term, intensive and thorough curriculum evaluation in which the district itself could and should engage, although it might not always have the means at its disposal. Scale-up funding provided those means. The role of the university side of the collaboration was to: develop the research design, guided by organisational patterns that existed within the school system; analyse data collected in classrooms; and report results. The role of the school district was to: direct the professional development required by the intervention units; coordinate the study across schools; and collect data. Interpretation of results and decision-making as the study progressed involved both sides of the collaboration.

When results associated with a particular curriculum intervention were ambiguous (as they sometimes were), the entire process slowed and the research design was revisited. For instance, one of the treatment units unexpectedly proved to be less effective than the comparison condition for 2 consecutive years. As a consequence, the unit was not scaled-up (Lynch 2008). When another curriculum unit yielded ambiguous results both overall and when data were disaggregated for 2 years, Scale-up replicated the study with different schools and employed a much tighter research design in the third trial (Watson et al. 2007). Although this delayed the research agenda, eventually a collaborative decision was made to move to scale-up the unit because the third trial yielded positive results under the more stringent design conditions.

McDonald et al. (2006) take a matter-of-fact approach to decision-making in scale-up: ‘Each [scale-up study] produces an essentially dichotomous answer – either the intervention does or does not lead to an improvement in a given set of circumstances’ (p. 16). However, scale-up’s decision-making process was neither clearly dichotomous nor dispassionate. Unexpected results and the need to thoughtfully revisit aspects of research design resulted in extensive, careful analyses and decisions that focused on the best courses of action for students, the school district partner, and the research study. The decision to scale-up a curriculum unit or eliminate it was ‘co-owned’ by scale-up’s school district and the university researchers.

In the era of No Child Left Behind (NCLB), school administrators might actively seek partnerships to test an intervention to remedy a specific problem if the intervention is believed to hold promise for meeting well-defined needs (Dahlkemper 2003; Lewis 2003; Daniel G. Bugler, personal communication, September, 2006). Although there might be instances when researchers approach a school district out of the blue to try an innovation, scale-up’s experience suggests that school districts are unlikely to expend extensive resources without some assurance that improved student outcomes are likely to ensue, especially if a goal is to scale-up the intervention.

In research collaborations that involve scale-up, there is a group of goal-oriented early innovators including both researchers and school district educators. Other teachers are gradually introduced to the intervention and go along as it scales up. Still others remain estranged from the intervention for a variety of reasons, no matter when they encounter it. In this view, researchers and educators both are interveners in the scale-up environment. Over time, the intervention either takes root and is institutionalised, or it dies out. McDonald et al. might refer to this as a context-specific test of the efficacy of intervention at the level of the school district. When middle school science curriculum units or the like are studied as scaled-up research, then counting spread across schools makes sense, yet is too limited.

Scale-up experienced ongoing negotiation and problem-solving, bolstered by goodwill and considerable efforts to interpret results in a way that would result in a sound course of action for scale-up. An alternative view of scale-up suggests a reconsideration of what is actually being spread. When a school district adopts an intervention or restructuring model, in the longer view, information about the innovation moves through the system. Information includes student outcome data, changes in teacher beliefs, norms and principles, and declarative and procedural knowledge about the innovation itself. Information about the research goals, methods and outcomes is also distributed, including contextualised knowledge about the innovation’s progress and who is involved, resistant or simply going with the flow.

During scale-up, middle school science teachers became involved with aspects of information flow in unanticipated ways. For instance, science teachers were asked to implement the intervention units with fidelity, while holding modifications to a minimum. Teachers asked, quite reasonably, about what exactly constituted fidelity of implementation and its parameters. Fidelity guidelines that were subsequently developed were as much a product of the science teachers' input as the researchers' (Lynch and O'Donnell 2005). For example, fidelity guidelines indicated that that teacher-developed homework and assessments not specified by the curriculum units were fine, but videos and Internet resources related to the units' concepts were not. Another example showed that, when one intervention unit proved to be less effective than the district's business-as-usual curriculum on the same topic, the teachers were sought out by the intervention unit's developers. Subsequent revisions of this unit were based in part on the teachers' input. Although this unit did not scale up, scale-up's partner-teachers' ideas will affect future versions of the unit in other school districts.

School Policy Climate

Principles, norms and beliefs are greatly affected by the school district's policy climate, which directs resources, professional development and incentives/disincentives to teachers. This sends a message about how the school district 'higher-ups' value a study. Scale-up's school district partner is large, influential and highly regarded. It is also becoming more diverse socio-economically, ethnically, culturally and linguistically. Predictably, because there are achievement gaps in science (and other subjects) between various demographic student subgroups, the school system must work hard to find new ways of reaching and teaching its increasingly diverse population in order to maintain its reputation. This was a priority of the strong and highly visible superintendent who has initiated several successful and highly publicised programmes to reduce achievement gaps (Weast 2000). This policy climate existed throughout scale-up and corresponded with the superintendent's mandate to improve student achievement for African American and Hispanic students. scale-up's goals aligned with school district policy goals, making it an opportune time for research on reducing science achievement gaps (Lynch et al. 2007b).

Even in a favourable policy climate, competing mandates created tricky cross-winds for both school district science educators and university researchers during scale-up. The study's initial goal was to compare the effectiveness of three different curriculum units with the business-as-usual curriculum materials. However, 2 years into the study, the district's central administration called for the development of new science curriculum guides aimed precisely at a new state curriculum framework. The district science office complied and formed teams of teachers to write the new middle school science guides. Thus, completely unanticipated, somewhat different comparison conditions were born during scale-up, a research programme that relied upon a series of quasi-experiments. Middle school science teachers in this district might be involved in implementing scale-up's curriculum units, or the development and implementation of the new locally constructed guides, or both. This messy situation shows how the school policy climate, while favourable for scale-up research on equity issues, could blow in new directives that are potentially confounding to the research design, which potentially could place science teachers and researchers in conflict. Although scale-up rode out these competing mandates, by

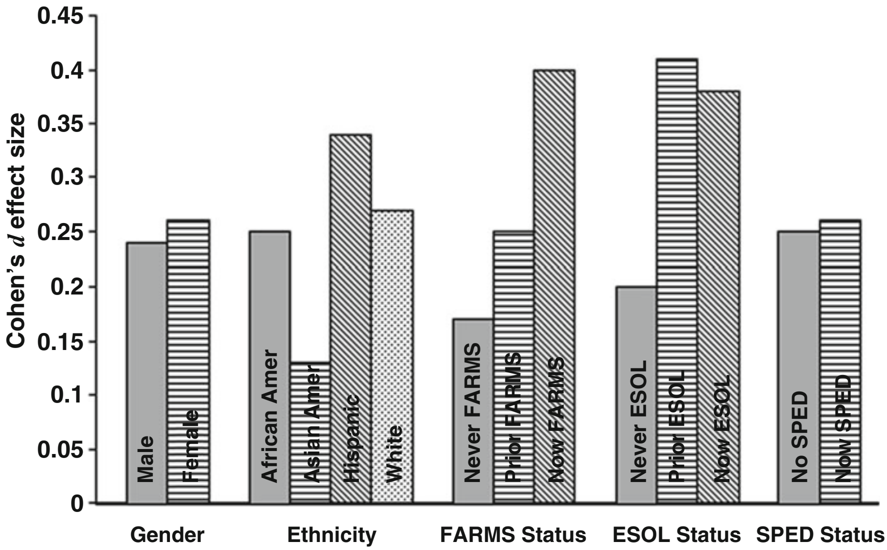

Fig. 61.1 Cohen's *d* effect sizes for *Chemistry That Applies* (2002–2003) according to gender, ethnic group or eligibility for Free and Reduced Meals Status (FARMS), English for Speakers of Other Languages (ESOL) or Special Education Services (SPED)

the end of the study, the comparison condition had been somewhat changed. It included the new locally produced guides, as well as the older menu of curricular options. Teachers' attachment to the new guides developed by local teams could affect the sustainability of scale-up's interventions after funding ended, despite the fact that two intervention units produced evidence indicating overall effectiveness and potential to close achievement gaps.

Assessment Feedback and Scale-up

Scale-up's initial effectiveness studies for the first curriculum unit, Chemistry That Applies (CTA) (State of Michigan 1993), showed significant mean differences on a curriculum-independent assessment of the target idea (conservation of matter) for 2 consecutive years. Disaggregated data showed that CTA was more successful than the business-as-usual curriculum materials for virtually all demographic subgroups of students (Lynch et al. 2005). This included student subgroups under-served in science education, such as students eligible for FARMS, ESOL or special education services, or African American or Hispanic students (Lynch et al. 2007b). CTA's overall effect size was 0.25 and ranged from 0.25 to 0.41 for under-served subgroups (see Fig. 61.1). Figure 61.1's representation of results made a compelling case to district science educators for CTA's scale-up. Measures of student engagement and goal orientation also pointed in a positive direction for the unit. Video data from classroom observations created insights about how the curriculum unit was actually functioning in the classroom to help students to learn (Kuipers et al. in press).

Information about the CTA unit spread, emanating not only from teachers, administrators and researchers, but also from students who had received the intervention and their parents. If student responses were positive, then teachers also were more likely to respond positively. Crucial to the successful scale-up of an intervention, however, is capturing and reporting solid student outcome data early, rather than relying solely on impressions of the unit. Some teachers liked CTA, some found it repetitious and others thought that they could teach the target concept better without the unit. But 2 years of data indicated that, overall, CTA was more effective than the standard fare, especially for under-served subgroups. Thus, the reciprocal relationship between the intervention's spread and student responses to it seems obvious *if* researchers can make the results publically accessible in a timely fashion. This increased CTA's chance of going to scale.

Scale-up was deliberately designed not to be an accountability system that could link student outcome data to teachers or schools. Rather, the goal was to generalise to the entire school system, with disaggregated student data providing an evidence-based voice from student subgroups that might not ordinarily be heard when making curriculum decisions. Although two of the three units scaled up over the duration of the study, and the public nature of the scale-up's data dissemination made the intervention research hard to ignore early on, it remains a question whether the study of the effectiveness of the units and their scale-up would have had more impact if there had been a direct linkage to classroom performance within schools.

An Organised Agenda for Scale-up

In school districts, interventions are constantly introduced, but quickly disappear: an administrator buys some software for schools to use; a professional development effort pushes a particular approach for instruction; or the state assessment system changes and so must teachers' everyday assessments. Such interventions can be fleeting because they were never really evaluated in the district and later subjected to decisions based on beliefs or fluctuating funding levels. Scale-up research is based on accumulating evidence of an intervention's effectiveness in different contexts; typically, school districts cannot do that sort of painstaking research (cf McDonald et al. 2006). Scale-up's studies could not have occurred without substantial research funding. Many decision-makers claim to want such evidence for better decision-making.

The ability to demonstrate an intervention's impact seems absolutely necessary but, oddly enough, probably not sufficient for spread and sustainability (cf Borman and Hewes 2002; Desimone 2002). Because most interventions require teachers to do things differently and often demand additional work and skills, the justification for the inevitable extra effort would be to add value for students or teachers. Even when outcomes are positive, some interventions fade because they are too labour-intensive, require too much change or have prohibitive maintenance costs. Teachers are faced with competing mandates. The effort associated with any one might not seem worthwhile, given an onslaught of innovations with differing priorities. If an intervention actually reduces teachers' work/effort while increasing student outcomes, it is likely to go to scale. Examples of scalable, sustainable innovations are scarce, particularly if they require changing beliefs, norms and principles.

Metaphor and Theory for Scale-up

Eagles in the Anacostia and Scale-up

Coburn (2003) and McDonald et al. (2006) contributed to the under-theorised study of scale-up in education. Coburn's definition includes often-neglected normative *outcomes* of scale-up at the school district level: depth, spread, sustainability and transfer of ownership. In contrast, McDonald et al.'s view is primarily *methodological*, given their vantage as managers of the knowledge diffusion from IERI scale-up portfolio. This chapter provides a practitioner/researcher view of a scale-up research study, emphasising conditions necessary for an intervention to go to scale; the flow of information is crucial, including its accumulation, interpretation, representation and presentation to stakeholders, and dissemination to a wider audience.

An analogy could illuminate the importance of information flow in a scale-up research system; it would require a situation in which one thing is obviously scaling-up, while something less obvious, but fundamental to growth and change, actually creates conditions for healthy proliferation. Ecological metaphors for scale-up have been used before (cf Cohen et al. 2001; McLaughlin and March 1978) and could be helpful here.

The Anacostia watershed of the Potomac River in Washington, DC, runs through a socio-economically stressed, ruderal area, where natural beauty competes with human neglect. Nonetheless, bald eagles were reintroduced to their ecological niche, and their population has been steadily increasing (Planet Maryland, March 21, 2001). The eagles, analogous to an educational intervention, are scaling up. Eagles are easy to spot; they are symbols of environmental health and wildness; and they have a patriotic connotation that allows them more public support for protection than other species. Because the watershed is constantly cleaned up, it can support a bald eagle population, as the media happily report. This environment has improved in several ways, but probably the most important is the healthy *flow of biomass* (fixed carbon) throughout the ecosystem that allows the eagles to find the fish that ate the plankton that fixed the sun's energy in carbon–hydrogen bonds. Thus, although the eagles are a visible symbol of scale-up, what has actually improved is the health of the system through better natural biomass cycling. In the Anacostia watershed, too much human trash or storm sewage runoff could affect the healthy cycle and lead to fewer eagles. Similarly, if eagles faced stiff competition for their food source from other introduced species, they could die off or find a better place to live. Biomass flow is analogous to the movement of information in a school district successfully involved in scale-up efforts. Poor communication or mixed mandates would impede the flow of information about the progress of an intervention going to scale, eventually resulting in its extinction.

In order to scale-up, the intervention should fit the school district's needs (like the ecological niche occupied by the Anacostia's eagles). The district probably is best at determining its needs, and a close, long-term collaboration with researchers is a good way of finding or developing a likely intervention. The district's policy environment further determines the intervention's success by creating incentives or disincentives for it to go to scale. For instance, if middle school science students are newly required to take high-stakes tests that assess their abilities to reason from evidence, and if the intervention can be shown to encourage such reasoning, then the intervention is likely to have a greater chance of success. If the assessment system relies on factual minutia covering a lot of ground, but does not require reasoning from evidence, the intervention might be doomed despite its success in helping students to reason deeply.

It is unlikely that any large educational entity would expend resources in moving an intervention to scale unless the policy climate demands or supports it. This could include initial buy-in from administrators and teachers. But eventually, convincing, positive results must flow from the students themselves, influencing decision-makers' and teachers' beliefs, values and attitudes. The ability to stream accurate information into the environment depends on the mechanisms already in place within the school district (email, accessible websites, professional development meetings, human networks, policy systems and administrative hierarchies) and how well the researchers can tap into them or create new ones. In severely stressed school districts, scale-up is difficult because positive information gets lost in the detritus of bad news or a swirl of new initiatives that roil through the schools.

Scale-up research can bring external funding for new resources and services for teachers and students. To sustain the intervention at scale, a commitment for continuing support is crucial as research funding comes to an end. If feedback on student learning was vital to the intervention, it must continue. If professional development meetings for teachers were the means to exchange of information on improved implementation, then such meetings must persist.

Scale-up researchers inquired about existing, sustained, scaled-up interventions in science in its partner school district. There were two examples (B. Hansen and M. Szesze, personal communication, February 5, 2004). In one instance, a middle school environmental education programme requiring overnight stays at an outdoor centre had been in place for decades. It is integral to the middle school science programme and is a rite of passage for students who might never have been 'away at camp'. It is one person's full-time job to manage this programme for the entire district. A second example is 'kit-based elementary school curriculum units', formerly funded through an NSF grant. This intervention is sustained by employing a full-time science equipment czar whose job is to procure equipment inexpensively for the kits, package it and send it off to elementary schools. His role expanded to include procurement for secondary school science programmes (including equipment for scale-up's interventions) and is fully integrated into the system. Just as the

Anacostia's eagle population is unlikely to be sustained without continuous human stewardship, it seems likely that relatively sophisticated education interventions also require ongoing stewardship, something that ought to be acknowledged and built into scale-up research if sustainability is a serious goal.

Activity Systems in Scale-up Intervention Research

The ecological metaphor for the scale-up of eagles in the Anacostia and the scale-up of science curriculum units in a large school district suggest overlapping, interrelated systems and layers of complexity, as well as the human actors crucial to scale-up and sustainability. Activity theory can help to explain scale-up's research programme, and more generally capture the complexity of relationships and meanings for the scale-up of education interventions in school systems. Activity theory's roots come from animal evolution and the natural environment, but it has been applied in human cultural evolution. What used to be ecological and natural becomes economic and historical (University of Helsinki Center for Activity Theory and Developmental Work Research 2006, p. 1). According to Linda Gilbert (1999), it is a development of socio-cultural theory, with much in common with current learning theories that marry notions of distributed cognition and situated cognition. There is a common focus on the interaction of the individual with the environment in gaining or using knowledge, with origins in the work of Vygotsky and his follower Leont'ev (1978). It neither is a theory in a strict interpretation of the term, nor is it predictive. Rather it is a powerful and clarifying descriptive tool and can be viewed as a general conceptual system. John Carroll (1997) describes activity theory:

> The object of description in this approach is an "activity system," the ensemble of technological factors with social factors, and of individual attitudes, experiences, and actions with community practices, traditions, and values. Activity theory emphasizes that these ensembles are essentially contingent and changing, that human activities are mediated and transformed by human creations such as technologies, and that people make themselves through their use of tools…Activity theory shifts attention from characterizing static and individual competencies toward characterizing how people can negotiate with the social and technological environment to solve problems and learn, which subsumes many of the issues of distributed and situated cognition (p. 512).

According to Graham Nuttall (2000), although activity theory research sometimes focuses on the use of computers as technological tools, it is also used as the basis for the generic analysis of the patterning of classroom experiences. According to Wells (as cited in Nuttall 2000), an activity is a relatively self-contained, goal-oriented unit, such as carrying out an experiment or writing a story. It consists of a series of behaviours or tasks that follow an expected pattern to achieve a goal, held together by the mutual interrelated expectations of participants (although how it is carried out can vary in time and place). Activity theory allows researchers to take a socio-cultural perspective in understanding how diverse students learn. On the other hand, some researchers equate student activities with 'learning', without direct reference to what might be occurring in students' minds; this idealises participation in

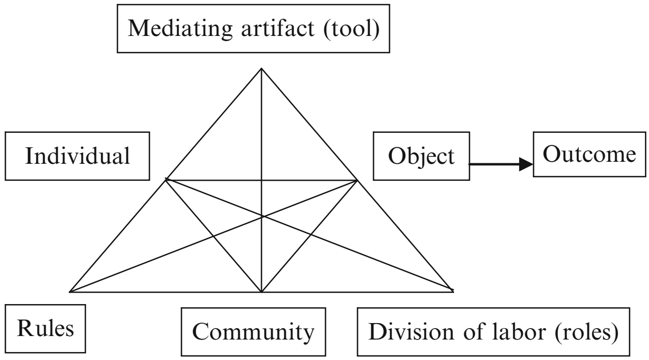

Fig. 61.2 Model of activity system (Adapted from Engeström 1992)

classroom activities as both the process and an end of learning. Nuttall (2000) believes that there are serious problems with this assumption, including the difficulty in interpreting what the activities of students mean, because of students' varied cultural backgrounds. Students might display interest when they in fact are not interested. Moreover, they could expend the least possible effort in carrying out tasks that are likely to be noticed or evaluated. Consequently, Nuttall urges that researchers attempt to capture what is in students' minds (concepts), as well as attitudes and beliefs, but uses activity theory as the basis for research. Yrjö Engeström (1992) provides a framework to describe a mediated activity system which consists of individuals, colleagues in the workplace community, conceptual and practical tools, and the shared objects (similar to objectives) as a unified and dynamic whole, depicted in Fig. 61.2.

Student Activity System

In scale-up research on middle school science curriculum units, the first activity system to consider is that of the student (individual) who is learning with the new curriculum unit, the mediating artefact or tool (see Fig. 61.2). The enactment of the curriculum unit in the classroom requires the student to follow rules in a community that consists of other students and the teacher. The teacher defines the division of labour in the classroom, further shaped by the curriculum materials and other students' actions, particularly students who are organised into laboratory groups. The object for the student is to learn the concepts from the curriculum unit, scaffolded by the teacher, curriculum materials and student peers, as the unit is enacted. The outcomes consist of laboratory journal responses, performance on assessments and grades. Improved understanding of complex science ideas is the ultimate outcome. Although the student was not much aware of it, in scale-up research, the disaggregated student outcome data made the most compelling public case for the intervention's impact.

Teacher Activity System

Concurrently, the teacher activity system sets the teacher's object as the implementation of the intervention unit, aided by professional development experiences and direct interactions with the written materials. In scale-up, the tool is the curriculum unit for both teacher and student activity systems. Each unit also has a teacher manual that guides the teacher to further explain the object. The teacher should follow the rules of the school and district, as well as those of the professional development and science teaching communities engaged in the study. The rules for teachers engaged in a scale-up research study might differ somewhat from those for teachers who are using the tool in a more routine way. In an effectiveness research study, the teacher should use the tool as intended/implied by the curriculum materials in order to ensure that the research is valid. Teachers also determine student division of labour and interact with other professionals who assume roles such as peers/coaches, supervisors, evaluators and researchers. The teacher's immediate outcome is the perception that the unit's lessons are going well or failing, discerned through students' daily interactions and cumulative work. However, if the research also provides collective measures of positive student outcome data in other classes and in other schools, the teacher has another way of weighing the unit's effectiveness. Thus, even if individual teachers have doubts, there is a feedback mechanism that can reassure them.

Researcher Activity System

In scale-up, the research team consisted of university researchers, science education administrators, evaluators and teacher peer/coaches. The object for this activity system was to study the curriculum unit's (tool) impact and scale-up. Each member of the research team had a specialised role, while keeping the interests of classroom teachers and students in mind. Researchers operated in the system of rules set for the project, as well as rules of the school system and the larger educational research communities. Each member of the research team participated in different kinds of actions related to the object, including the formal and informal collection and analyses of evidence, fully aware that valid student outcome data are crucial to scale-up research.

In summary, there were three different activity systems in play (student, teacher, researcher) in scale-up. Each had much in common with the other, in membership, community and rules. All relied on the same tool (the curriculum unit) and object (to achieve positive student outcomes that are valid and reliable, to be distributed publically). Activity theory captures the complexity of scale-up research, while fixing common terms and ideas to explain what is occurring. The extent of agreement between the activities systems related to a common object probably can predict an intervention's degree of success. The four conditions identified in this chapter as crucial to the scale-up of new curriculum materials (close school district/research collaboration, a positive climate for the intervention, the collection of student outcome data, and the system that makes data accessible to move the scale-up research agenda) help the three overlapping activity systems to adhere and remain congruent.

On the other hand, the student, teacher and researcher activity systems, no matter how compatible early on in scale-up, soon faced competition. Middle school students come to school with many competing goals (social and academic), some of which could conflict with object/intervention of a science curriculum unit. The teacher activity system focuses on the intervention science curriculum unit, but teachers have other objects as well. Teachers participating in scale-up voiced concerns about the amount of time that intervention units take and whether this leaves sufficient time to cover other topics than mandated by the new state curriculum and high-stakes assessment system. For the researcher activity system, school district science collaborators were subject to competing accountability structures. Their jobs demanded participation in other activity systems, such as designing new middle school science curriculum guides. They used the information gained from scale-up research to influence the design of the new guides and the associated professional development. Ultimately, it was the flow of information that was really scaling-up.

Summary

This chapter is intended to advance theory-building for scale-up research. Prior articles by Coburn (2003) and McDonald et al. (2006) offered different views of scale-up: one is normative and retrospective; and the other is methodological and general. In contrast, this chapter provides a highly contextualised perspective on scale-up from the ground level, as this study developed over 6 years. Metaphors such as the scale-up of eagles in the Anacostia illuminate the scale-up of middle school science curriculum units in a large public school district. This metaphor is important because it demonstrates that what might be obviously scaling up could be dependent on the underlying health of the information system that nurtures it. These complex interactions are further explored from the standpoint of activity theory. An understanding the congruence of overlapping activity systems provides a way in which to see the potential for an intervention to go to scale. Moreover, the continued alignment of important activity systems is likely to determine the sustainability of the intervention over the long run. Changes in human activity systems, no doubt, are inevitable and responsive to factors outside any one given school system. Seeing such changes as natural, but not necessarily inevitable, is helpful in understanding the ecology of educational reform and shaping its future.

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Part VII
Argumentation and Nature of Science

Chapter 62
The Role of Argument: Learning How to Learn in School Science

Jonathan Osborne

> Learning starts when you leave the classroom, when you start discussing with people around you what was just said. It is in conversation that you start to internalize what some piece of information meant to you. John Seely Brown, cited in Don Tapscott (2009, p. 137)

Contemporary psychology sees learning as a process in which knowledge is socially constructed through the use of multi-semiotic tools (though predominantly language) – that is, through dialogue and social interaction. However, the discussion of ideas within the classroom, an activity which the above quotation suggests might aid learning, is rare. Indeed, there is an urgent need for more of this kind of opportunity to be provided in schools. The unfortunate feature of much contemporary practice in education – and particularly science education – is that it is dominated by the notion that its primary function is to communicate a body of knowledge (Csikszentmihalyi and Schneider 2000; Nystrand et al. 1997). In this chapter, drawing on a growing body of research, it will be argued that such practice has several consequences for school science. First, it undervalues teaching and learning about the epistemic base of science – the principal feature of science that has led to a respect for rationality and a belief in the value of evidence in contemporary culture. Second, limiting the opportunity for students to consider and explore the ideas of science alienates many students from science. Third, it limits the number of learning pathways available to students, thus making the teaching and learning of science less effective than it might be. And, fourth, it limits the potential of school science to offer opportunities for students to work collaboratively, think creatively and critically, and support each other's learning. Rather, providing students with opportunities to engage in argumentation in school science, it will be argued, offers a means of transcending such constraints, developing students' capacity to collaborate and, at least tacitly if not explicitly, teaching them how to learn. In short, the adoption of

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a more discursive or dialogic approach to the teaching of science can enhance the quality of the pedagogic practice in school science. Research which has explored how that can be achieved is the final consideration of this chapter.

What Is Meant by Argument?

Argument in everyday language commonly carries with it a pejorative meaning associated with confrontation and feelings of discomfort. This is the notion of argument as war (Cohen 1995). For this reason, some prefer to talk about the process of discussion, reasoning or debate. Whilst this is understandable, what such terms fail to capture is that the resolution of problems or issues comes from contradiction or, as put in Gaston Bachelard's (1968) succinct summary:

> Two people must first contradict each other if they really wish to understand each other. Truth is the child of argument, not of fond affinity. (p. 114)

From such a perspective, argument is seen as something which is essential to the resolution of difference – an idea captured by Frans van Eemeren and Rob Grootendorst (2004) when they define argument to be a:

> …verbal, social and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of propositions justifying or refuting the proposition expressed in the standpoint. (p. 1)

'Argumentation' then is a term which refers to the process of constructing an argument and its justification whilst the term 'argument' refers to its substantive content. A more appropriate metaphor for argument would be to see it as a process of brainstorming – a process that results in an exchange and evaluation of ideas rather than their imposition by one side of their views on another. As Daniel Cohen (1995) suggests, this means that argumentation can be seen as a process of 'arguing for something' without necessarily arguing against anybody – a much more positive perspective.

Argumentation has three generally recognised forms: analytical, dialectical and rhetorical (Van Eemeren 1996). The application of analytical arguments (e.g. formal logic) to evaluate scientific claims has been extensive and pervasive. The capstone event of applying argumentation to the sciences was perhaps Carl Hemple and Paul Oppenheim's Deductive-Nomological Explanation Model (Hemple 1965) in which deduction was used as an account to establish the objectivity of scientific explanations. Stephen Toulmin's (1958) examination of argumentation was, in contrast, one of the first to challenge the 'truth' seeking role of argument, and instead, push us to consider the dialectical and rhetorical elements of argumentation. For Toulmin, arguments were field dependent as, in practice, the warrants and backings used to make claims are shaped by the guiding conceptions and values of the field. In science, what counts as evidence, and the theoretical assumptions driving the interpretations of that evidence, are consensually and socially agreed by the community (Longino 1990). From Toulmin's perspective, arguments consist of claims about the world which are advanced as statements of truth. These claims are supported by data whose connection to the claim is articulated through a warrant which justifies the significance of the evidence. Such warrants often rest on theoretical suppositions or backings which can be explicit, but are often implicit. Claims can also be qualified to show the extent of the domain in which they hold true and are commonly subject to rebuttals or counterarguments which might attempt to show why either the warrant, the data, or the qualifiers are fallacious.

What Toulmin offers is twofold. First, his achievement is to bring argumentation out of the reified context of academia and to show that it is an everyday activity and not the sole preserve of logicians and philosophers. In this context, argument is a universal and daily occurrence which occurs, for instance, in discussions about the best route to get from A to B as much as it does in academic discussions about the relative merits of competing explanations about climate change. Argumentation is thus a normative dialogic process rather than exceptional one. Its preeminent role is to serve a rhetorical function of persuading the listener of the validity of the speaker's worldview.

His second contribution is that his framework provides a meta-linguistic vocabulary for describing the features and elements of an argument. Providing such a vocabulary is important as it offers us both a schema for the analysis of argumentative discourse but, more importantly, a means of describing the linguistic function of the elements of an argument – a meta-level understanding which is an essential requirement both to develop teachers' theoretical understanding of argumentation and to provide a meta-language to describe the discursive function and purpose of the many elements of an argument.

The Role of Argumentation in Learning Science

Since the inception of contemporary science in the sixteenth century, science has accumulated a large body of knowledge about the material world. Much of it – for instance, the idea that diseases are transferred by microscopic organisms, that matter is made of atoms or that day and night are caused by a spinning Earth – have become commonplaces of contemporary culture. One of the primary goals of science education is to introduce young people to this body of knowledge and the explanatory accounts that science offers. The problem is that this canon of knowledge has acquired a reified status in the minds of teachers and curriculum developers and the hard won struggle to achieve this understanding has been forgotten. The consequence is that science tends to be portrayed from a positivist perspective where scientific claims are seen as logically and self-evidently deducible from a limited set of empirical premises. To the neophyte student of science, then, the subject appears to consist of an 'unmitigated *rhetoric of conclusions* in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal and irrevocable truths' (Schwab 1962, p. 24) – in essence a body of knowledge which is unequivocal, uncontested and unquestioned (Claxton 1991).

Moreover, the positivist perspective is rooted in a view that there is a sharp distinction between statements which are based on what is observable and statements that are a product of our theories about the world. Observation and experiment are the neutral and, more importantly, value-free foundations on which knowledge in science rests. The consequence of the excision of the human and social element for many pupils is succinctly captured by the following extract taken from a focus-group study of young (age 15/16 years) students' impression of their school science courses (Osborne and Collins 2001):

> Cassie: With science it's solid information and you've got to take it down…
> Cheryl: …so when they teach you science you know that this is it, okay? There is nothing, you can't prove it wrong,
> Leena: In what way does that make it different to other subjects though?
> Shakira: I mean you just have to accept the facts don't you?

Teaching science in this manner, however, is to misrepresent the scientific endeavour. This is not to say that inductive generalisations of empirical observations are not a methodology that science uses. Indeed, they are, or at least were, very much a basic feature of the taxonomist, the astronomer and the geologist. However, the crowning glory of science is not observation and experiment but the explanatory theories it has developed to explain the material world (Harré 1984). Such theories are the product not of observing how the world *is* but rather of imagining how the world might *be* or *has come to be.* It is this that is the core creative element of science. Thus, Copernicus' achievement was to reject the self-evident perception that all the stars rotate as if stuck in fixed positions on some celestial sphere, and to imagine whether an Earth which orbited the Sun would offer a simpler explanation of the retrograde motion of the planets. Likewise, Darwin's achievement was to ask how there was such diversity in species even on adjoining islands and to imagine a process which might have led to such variation. Ronald Giere et al. (2006) capture this additional and important dimension of science with the model in Fig. 62.1.

What this model shows is that models of the world, that is, theoretical constructs enable prediction. The extent to which the data agree or disagree with the prediction then needs to be examined – a process that is rarely straightforward. Rather than a single theory or conjecture to be checked, often it is the case in science that there are two (or more) competing theories. Then the key activity of scientists is evaluating which of these alternatives does, or does not, fit with available evidence and, hence, which presents the most convincing explanation for particular phenomenon which is the focus of inquiry. To the extent that any given theory survives this process of testing, it is believed to offer us reliable knowledge of the world. Such knowledge is hard won, dependent as it is on the creative imagination of scientists and explains why Rom Harré (1984) sees scientific theories as the apotheosis of scientific achievement.

The role of argument in science and science education is discussed more extensively by Sibel Erduran and Marilar Jimenex-Aleixandre (2008) but in essence its role is summarised by Rosalind Driver and her colleagues (2000) who argue that:

> Science is a social practice and scientific knowledge the product of a community. New knowledge does not become public knowledge in science until it has been checked

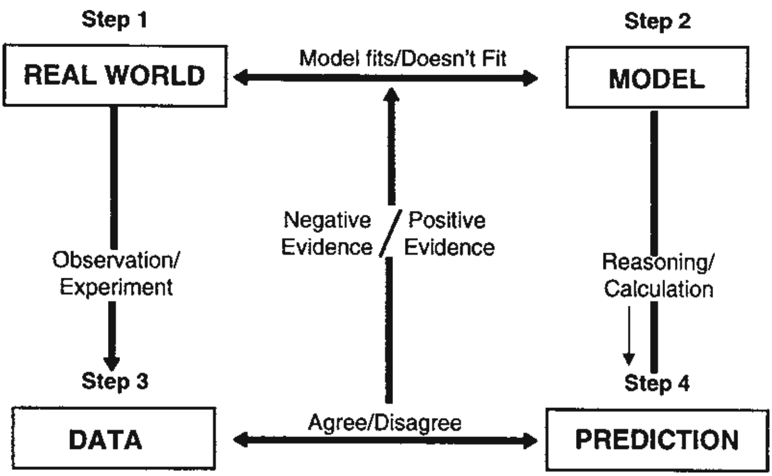

Fig. 62.1 The four elements of a complete scientific episode (Giere et al. 2006)

> through the various institutions of science. Papers are reviewed by peers before being published in journals. Claims made in published papers are scrutinized and criticized by the wider community of scientists; sometimes experiments are repeated, checked, and alternative interpretations are put forward. In this process of critical scrutiny argument plays a central role. (p. 296)

Joseph Schwab argued that this meant that the teaching of science should be an 'inquiry into inquiry' (Schwab 1962). Whilst this view has been articulated in a variety of different forms from teaching science as a process (AAAS 1967), to teaching science through inquiry (National Academy of Science 1995) where it is argued that 'inquiry into authentic questions generated from student experiences is the central strategy for teaching science' (p. 31), to teaching a set of 'ideas-about-science' (Millar and Osborne 1998), the argument has remained basically similar. That is, an education in science has a responsibility to provide some insight into the inner workings of science – a knowledge of science-in-the-making (Latour and Woolgar 1986) – and knowledge, moreover, which is essential for the future citizen who must make judgements of reports about new scientific discoveries and applications (Millar and Osborne 1998). The growing adoption of this view in the context of science education means that there has been a shift from presenting science as a body of objective 'facts' about the world to one in which science is seen as a set of ideas which are the product of testing and evaluating them against a body of evidence and data derived from the material world (Duschl 2007).

A good example of what this might mean in the classroom context comes from one of the most foundational scientific beliefs of contemporary society – the idea that the phenomenon of day and night is explained by the fact that we live on a sphere which rotates completely once every 24 h, illuminated by a fixed sun. To start, there are many good arguments against such a view. First, it is the sun that appears to move. Second, if it was moving, the speed at the Equator would be in excess of the speed of sound and surely we should be flung into space? Third, if it was spinning, when we jump up, would we not land in a different spot? Few people know or consider these counterarguments and how they may be rebutted. Instead, the explanation is presented as it was unproblematic and common sense when it is the everyday conception that the Sun moves is more self-evident. Furthermore, few people know the two pieces of critical empirical evidence that support the standard scientific account. Consequently, rather than the idea being presented or argued for as an evidence-based explanation and, in so doing, exposing the inner workings of science, the explanation is commonly offered as a form of dogma. In contrast, students could be asked to examine the merits of the competing arguments in the light of the available evidence. The failure to consider the epistemic basis of science has left too many students with simplistic views of science which sees it as a process of deriving 'facts' about the world from inductive generalisation made from repeated observations (Driver et al. 1996).

Why does the teaching of science so commonly fail to explore the nature of science? The answer is complex but many curricula emphasise the foundations or basic concepts of science – the names of the planets, the parts of the body or the distinction between chemical and physical reactions. Whilst such knowledge is of some value, it is only of value when placed in a context which gives it some meaning. A set of facts in science no more constitutes anything of substance than a pile of bricks constitutes a house (Millar and Osborne 1998). Then there is the fact that most teachers of science are a product of an education in science which has given them few insights into the nature of science itself (Lederman 1999). And, if teachers of science do not hold a contemporary model of science, what chance is there of their students developing a better understanding? But perhaps the dominant reason is that much school science is strongly framed by the sets of national or state standards and assessment frameworks which place a considerable emphasis on the acquisition of fragmented aspects of conceptual knowledge. Much of the reason for this is that it is considerably easier to write items that test students' ability to recall factual knowledge than to write items which test their ability to evaluate competing interpretations of a given set of data (Osborne and Ratcliffe 2002).

Correcting the common misconception of the scientific endeavour generated by school science, however, can be achieved by providing an opportunity to explore the reasons for believing scientific ideas. Only in this manner will school science lay bare the rationality that lies at the heart of science and technology – essentially a commitment to evidence as the basis of belief (Siegel 1989). This, in turn, can only be achieved by offering not singular explanatory accounts but *plural interpretations* of phenomena (Monk and Osborne 1997). By providing the opportunity to discuss and argue about their competing merits, students will be engaging in a normative epistemic practice of science. This will provide the insight that disagreement in science is not exceptional – a key feature of any understanding about science required to engage with science in the public domain. For many teachers of science, this is a difficult idea to accept for their rhetorical project is to persuade students of the validity of the scientific world-view (Osborne 2001). Such goals are not normally achieved by serious consideration of alternative explanations.

Yet the irony is that there is good evidence that permitting students to consider plural alternatives leads to a more secure understanding of the accepted scientific idea. For instance, Cynthia Hynd and Donna Alverman (1986) found that, if students were given texts that not only explained why the right answer was right *but also explained why the wrong answer was wrong*, and students were provided with an opportunity to deliberate about the merits of the competing explanations, then students' conceptual learning, compared to a control group, was enhanced. Likewise, Christine Howe et al. (1990, 1992) found in studies, based on a comparison of the learning of groups that held differing preconceptions compared to those who held similar preconceptions, that the groups consisting of those who held different ideas consistently made greater progress. Indeed their finding was that those who worked in groups of learners who held similar ideas made no progress whatsoever.

More evidence for the value of argumentation for conceptual learning comes from the research conducted by Anat Zohar and Flora Nemet (2002) working with two classes of 16–17-year-old students studying genetics. Their approach required the teacher to permit students opportunities to engage in argumentative discourse about the appropriate answer to specific problems. They then compared the outcomes of their work with similar control classes taught in a more traditional manner. Three statistically significant findings emerged from their work: first, the frequency of the students who *did not* consider biological knowledge was higher in the comparison group as compared with the experimental group (30.4% vs. 11.3%); second, the frequency of students who used false considerations of biological knowledge was higher in the comparison group when compared with the experimental group (16.1% vs. 4.8%, respectively); and, finally, the frequency of students who correctly considered specific biological knowledge was higher in the experimental group as compared with the comparison group (53.2% vs. 8.9%, respectively) (Zohar and Nemet 2002).

Providing students the opportunity to make judgements about the basis of belief by engaging in argumentation demands the use of the higher-order cognitive processes of analysis, evaluation and synthesis (Bloom 1956). In turn, these require students to clarify their prior knowledge (Aufschnaiter et al. 2008). Thus, learning to argue is both a process of *learning to think* and a process of *arguing to learn* (Andriessen 2006). More fundamentally, the demands that it makes on higher-order processing skills will make science education a context which contributes towards developing student skills to think critically and creatively and to work collaboratively – all skills which an increasing body of research indicates are essential in the world of work in the coming decades (Gilbert 2005; National Research Council 2008; Tapscott 2009).

How Does Argumentation Support the Learning?

Why should engaging in argumentation have these effects? Argumentation requires the participant to (a) listen to what the other person has to say which, in and of itself, is a social skill which many young students lack, and (b) to compare and contrast the idea that they have just heard with their own thinking – a cognitive action which requires a student not only to reflect on their own ideas and cognition but to reflect on the ideas of others. Such thinking utilises the higher-order skill of comparison and contrast and, consequently, as Michael Billig (1996, p. 41) suggests, 'learning to argue may be a crucial phase in learning to think'.

Moreover, this process of juxtaposing ideas develops an evaluative epistemology – in which the individual begins to see their ideas for what they are – as claims which need to be assessed in the light of competing alternatives or ambivalent evidence. Individuals who do not adopt such a stance hold personal epistemologies which are absolute, taking their theories for granted essentially as statements about the way the world is. Alternatively, many young people hold a multiplist epistemology which sees all ideas as being of equal worth and with no criteria which could establish the relative merits of competing claims – essentially a highly subjective and individualist view of life. Deanna Kuhn (1999) argues for a developmental model of critical thinking in which young people start out as absolutists. Then, in adolescence, recognising that such a position is untenable, many shift to becoming multiplists – a position typified in lay terms by the response of 'whatever' to any challenge – a response which can essentially be understood as meaning that whatever you think is fine for you just as what I think is fine for me.

However, such a position is ultimately untenable as it denies the possibility that some solutions are better than others and gives free rein to those who might wish to hold ideas that might be considered racist or offensive. Those who hold a multiplist epistemology also lack any rational criteria for deciding about the merits of competing claims. As Kuhn (1999) argues:

> To be competent and motivated to 'know how you know' puts one in charge of one's own knowing, of deciding what to believe and why and of updating and revising those beliefs as one deems warranted. To achieve this control of their own thinking is arguably the most important way in which people both individually and collectively take control of their own lives. (p. 23)

It is only by considering alternatives – by seeking to identify what is not – that one can begin to achieve any certainty about what is.

Some insights into why this is so and how argument 'works' comes from the work of Stephan Ohlsson (1996). He suggests that it is possible to distinguish two principal forms of learning – *learning to do* and *learning to understand*. Learning to do – essentially skill-based learning of the kind required when learning to play a musical instrument, ride a bicycle or ski – requires practice and repetition. Learning to understand, in contrast, requires engagement in a variety of discourse acts which he defines as follows (Table 62.1).

All of these discourse acts are to be found in the kind of dialogic discourse engendered by argumentation. As Ohlsson (1996) argues:

> …this tentative taxonomy of epistemically relevant activities is short but surprisingly complete. Whatever else do we ever do when we talk or write, over and above describe, explain, predict, argue, explicate and define. Although there are many other types of speech acts (e.g. to promise, request and threaten) no epistemically relevant extensions to the taxonomy comes to mind. (p. 51)

Table 62.1 List of epistemic discourse activities (Ohlssson, 1996)

Discourse Activity	Description
Describing	To describe is to fashion a discourse referring to an object or an event such that a person who partakes of that discourse acquires an accurate conception of that object or event
Explaining	In the canonical explanation task, the explainer is faced with an event of some sort (e.g. the sinking of the Titanic, the demise of the dinosaurs) and fashions a discourse such that a person who partakes of that discourse understands why that event happened
Predicting	To make a prediction is to fashion a discourse such that a person who partakes of that discourse becomes convinced that such and such an event will happen (under such and such circumstances)
Arguing	To argue is to state reasons for (or against) a particular position on some issue, thereby increasing (or decreasing) the recipient's confidence that the position is right
Critiquing (evaluating)	To critique a cultural product is to fashion a discourse such that a person who partakes of that discourse becomes aware of the good and bad points of that product
Explicating	To explicate a concept is to fashion a discourse such that the person who partakes of that discourse acquires a clearer understanding of its meaning
Defining	To define a term is to propose a usage for it. When the term already exists in the language, the boundary between defining and explicating is blurred

It is important to note, however, that Ohlsson makes no distinction between the importance of each of these categories. For instance, they are not to be seen as a hierarchy reflecting increasing cognitive demand. It is reasonable to suppose, however, that some of them could be more epistemically demanding than others. Tentatively, I wish to argue that, following Kuhn (1991) and Miller (1987), some of these skills are more indicative of higher-order cognitive thinking. For instance, description is a relatively undemanding task that is often reliant on a mastery of language simply to convey the major perceptual features of an object. The task becomes harder when the object is not easily visible (i.e. when it is too small to be seen or too large to be imagined). In such cases, individuals have to resort to the use of analogy or metaphor to construct imagined entities (Harré 1986) which can form the basis of an explanatory account.

Evidence for the epistemic function of Ohlsson's set of discourse activities comes from the work of Micki Chi et al. (1989). In her study, eight college students were asked to explain to another what they understood from reading statements from three examples taken from a physics text. The four students who were more successful at solving problems at the end of the chapter (averaging 82% correct in the post-test) were the ones who had spontaneously generated a greater number of self-explanations (15.3 explanations per example). In contrast, the four students who were less successful achieved only 46% on the posttest and had generated only 2.8 explanations per example. Similar findings emerged from a later study with 14 eighth grade students for which the focus this time was on declarative knowledge of the functioning of the valves in the heart (Chi et al. 1994). Notably, the improvement for the students required to generate explanations was more significant for the more complex questions used to test understanding. Chi et al. postulate that the reason why such explanation is effective is that, having articulated an incorrect explanation, further reading of ensuing sentences (which always present the correct information) ultimately lead to the generation of a contradiction. The outcome of such conflict will require metacognitive reflection and self-repair by the student if resolution is to occur.

The exercise that Chi et al. conducted was essentially a decontextualised psychological experiment and not a process that lends itself easily to the classroom. In the classroom, it is small-group work and argumentation, however, which provide a naturalistic context in which self-explanation is both required and challenged – the very activities which Chi et al. have found to be so effective at enhancing student learning. Evidence that this is so comes from a review conducted by Noreen Webb (1989) of 19 published studies on learning mathematics and computer science. Her finding was that the level of elaboration of students' interaction with other students was related to achievement: those who gave high-level elaboration to other members of the group achieved more highly, whereas those offering only low-level explanations experienced no effect. Her explanation for this effect was that:

> In the process of clarifying and reorganizing the material, the helper may discover gaps in his or her own understanding or discrepancies with others' work or previous work. To resolve those discrepancies, the helper may search for new information and subsequently resolve those inconsistencies, thereby learning the material better than before…Furthermore, when an explanation given to a team-mate is not successful, the helper is forced to formulate the explanation in new or different ways. (p. 29)

Another important insight into the value of argumentation comes from the work of Giyoo Hatano and Kayoko Inagaki (1991). The data that they drew from many experimental studies of small groups working collaboratively on problems led them to draw three conclusions. First, students often produce knowledge that can seldom be acquired without such interaction – a point which was recognised by the Headmaster of Eton, a leading English private school, when he stated that 'we have always recognised two principles in education, which are first that young people teach each other more than adults think they teach them, and, secondly, that at least as much learning goes on outside the classroom as within it' (Eyres 2008, p. 1). Their second finding was that the nature of the knowledge acquired by the majority of the participants is very context-specific to the group, even when the structure and nature of the activity are very similar. That is, the variance between groups is large. Finally, they also found that the knowledge acquired within the groups by individual members differed considerably – that is, the intra-group variance is large. What this suggests is that the nature of the group dynamics has a considerable effect on the potential outcomes of any small-group discussions or argumentation.

To explain the enhanced potential for learning achieved by argumentation, Christine Chinn (2010) and I have developed a model, called the Questioning & Argumentation (QA) model, that attempts to explain how students' questions can initiate and sustain argumentation during group discourse (see Fig. 62.2).

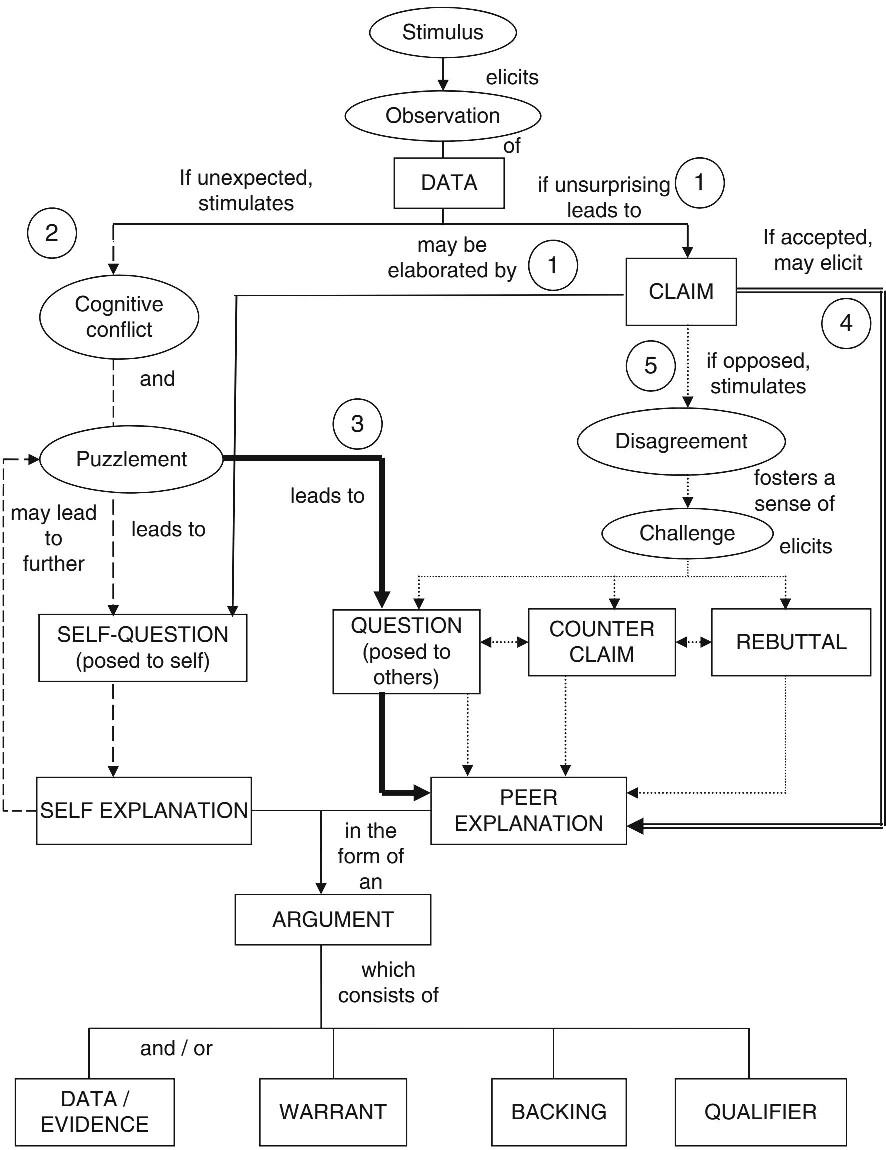

Fig. 62.2 The questioning and argumentation model

Developed from a set of empirical data, it describes a number of possible pathways that lead to the development of self-explanations (Chi et al. 1994) or peer explanations that are supported by questions that a student poses either to themselves or to others.

In this model, a stimulus presented to students serves as a source of data. The stimulus could be in the form of a demonstration, a discrepant event, or a problem in textual or graphic form which students are then asked to discuss. Observation of the data embedded in this stimulus can lead to a claim by the student of how and why things behave in way in which they do. This is a result of the student's attempt to make sense of, and to explain, the given phenomenon. If the observation is as expected, this claim can be further elaborated by self-explanations and justifications to back up the claim. This pathway is depicted by the thin, solid lines (1).

On the other hand, if the observation is unexpected, this stimulates cognitive conflict in the student. This puzzlement can then elicit a *self-question* posed by the individual to himself/herself, which subsequently leads to a *self-explanation*. This second pathway is illustrated by the broken, dashed line (2). In the course of formulating this self-explanation, the student can encounter further puzzlement, which then generates another self-question and self-explanation. During this process, the student attempts to reconstruct his or her activated mental model to bring it into closer alignment with the given data. This would then explain the body of research (Chi et al. 1989, 1994) which has shown that the cognitive activity of self-explanation supports knowledge construction. Self-questions and self-explanations can be overt or covert, depending on whether they are externalised. However, it is important to note that, for the student working in isolation (a form of individualisation encouraged by a direct instruction) pathways 1 and 2 represent the only means by which new knowledge can be constructed.

Alternatively, instead of talking to himself/herself, a student instead might verbally articulate the question to others, which would then elicit a *peer explanation*, as indicated by the bold, solid lines (3). When a student publicly makes a claim, this also can stimulate either agreement or disagreement amongst his or her peers. If this claim is accepted, other students can build and add to the proposed idea – depicted by the thick line (4). However, if this claim is opposed, it could foster a sense of challenge in students with alternative viewpoints. This could result in a rebuttal, which could be in the form of a counterclaim or a question, either of which might further elicit a peer explanation. This latter pathway is shown using dotted lines (5). The explanations constructed by the students during this group talk might consist of one or more components of an argument, namely, data, evidence, warrant, backing and qualifier. The interaction between the social and personal, mediated through questions, challenges and explanations, reflects the movement between inter-psychological and intra-psychological planes. In addition, it also promotes reflexivity, integration and the appropriation of knowledge.

What the QA model shows is how students' dialogue and questions to each other support the construction of evidence-based arguments. Questions are the essential pre-cursors of conflict. Whilst pathways 2 and 5 illustrate the role that conflict plays in argumentation and reasoning through the process of accommodation, pathways 1, 3 and 4 are based more on the concept of assimilation with students' ideas becoming increasingly elaborated by adding to pre-existing concepts. In some respect, this explains how both conflict and cooperation mediate the knowledge construction process. Furthermore, whilst pathway 2 depicts the role of cognitive conflict as an individual construct, pathway 5 shows how public discursive conflict can be resolved dialogically. But, perhaps more fundamentally, it offers some insights into why students' attainment in the dialogic classroom has more potential for learning. In such a classroom, all five pathways exist as possible ways in which understanding might be achieved. In the transmissive classroom, only pathways 1 and 2 offer a potential means of learning. Thus, the model not only offers an explanatory account for the mechanism by which personal and social construction of knowledge is achieved through questioning and argumentation but, more importantly, demonstrates why the dialogic classroom will potentially be a more effective learning environment.

Implementing Argumentation in the Classroom

For the teacher, the issue of how to establish argumentative discourse of high quality within the classroom is akin to an engineering challenge. Much effort has been expended by those working on computer-supported collaborative learning in exploring how this might be achieved (Andriessen et al. 2003; Linn and Bell 2000). However, many classrooms do not have ready access to such technology and their needs are both more prosaic and more complex – more prosaic in that the issue is simply one of how argumentative discourse can be implemented without any technology and more complex in that there is more to using such an approach than can be captured by any technology. The approach taken by the author and his co-workers has been to develop a pack of materials to support the professional development and learning of teachers (Osborne et al. 2004b) in collaboration with a group of eight teachers. This pack focused on six themes which were considered to be essential theoretical and pedagogical knowledge for any teacher wishing to adopt the use of argumentation in their classroom (see Table 62.2).

Crucial to teachers' attempts at innovative strategies, however, are the insights that come from observation of another teacher engaging in the practice in a context similar to their own. This enables critical reflection on the strengths and weaknesses of any novel practice and reflection on how it might be adapted to their own students and context. For this reason, these materials were supplemented by 28 video excerpts drawn from lessons of experienced teachers using argumentation. As Ernst von Glasersfeld (1989) points out, such video extracts are a far more powerful didactic tool than oral or written materials which are often, at best, only half understood. Video, he argues, has been responsible for the major advances in the teaching of sports in the past two decades. Likewise, we would contend, it has similar value for teachers' professional development.

Last but not least is the capacity for the use of argumentation as a pedagogic approach to enhance student engagement. Some direct empirical evidence for this comes from the work of Susan Nolen (2003). In a study involving 377 students in 22 introductory science classes in the ninth grade, she showed that shared perceptions amongst the students that their classroom focused on understanding and independent thinking positively predicted students' self-reported satisfaction with learning. The conclusion that she drew was that, 'in these classrooms where students perceive their science teacher as interested in student

Table 62.2 Six themes and knowledge needed by teachers

Theme	Knowledge needed by teachers
Introducing argument	Underlying the use of argument is a set of theoretical ideas about the elements constituting an argument, why it is central to science and how it might assist student learning. Such theoretical understandings are essential knowledge without which teacher pedagogy becomes simply the performance of a set of practices whose value and intent is obscure (Adey et al. 2003).
Managing small-group discussion	Small-group discussion is a central element of using argumentation in the classroom. Yet its use is relatively rare in the science classroom (Newton et al. 1999; Osborne and Collins 2000; Sands 1981) and standard pedagogical techniques of pairs, envoys, listening triads and jigsawing (Johnson, Johnson, and Johnson-Houlbec 2002) are unfamiliar to many teachers of science.
Teaching argumentation	Work on our earlier project with 12 teachers (Osborne et al. 2004a) had established that there are a number of pragmatic issues that confront teachers. For instance, teachers need to be able to define and value goals other than conceptual learning. Such goals and their value must be communicated to students. What are the different structures and lesson types that will promote argumentation? In addition, for many teachers, providing space to discuss erroneous ideas or misconceptions would seem, at least in the first instance, to undermine such a goal. Furthermore, teachers of science need to have some understanding of the scaffolds that will stimulate argument in small groups (Simon et al. 2006).
Resources for argumentation	Teachers of science need exemplars of materials and strategies that can be used to develop argumentation with their students (in essence a starter pack of ideas). In this case, a set of materials that had been developed by the teachers with whom we had worked initially were incorporated in the pack.
Evaluating argument	Once students have begun to engage in argumentation, teachers have to facilitate and scaffold the process. Doing so requires judgements to be made about the quality of argumentation. Many frameworks exist for evaluating argument, but most are reliant on Toulmin's framework and an appreciation of the need to identify which of these elements are present or absent in a given argument. Teachers need opportunities to analyse arguments and share their understanding of the relative merits of a range of arguments on a common topic.
Modelling argument	Part of the pedagogical knowledge associated with argumentation is an understanding of how to represent and communicate what the elements of an argument are to students with appropriate language. Exploring ways of doing this is an important part of the professional learning required to engage in argumentation.

understanding and independent thinking, rather than in the speedy recitation of correct answers, students were more likely to have productive and satisfying learning experiences' (p. 365). Whilst the data to support the view that student engagement in a dialogic classroom is more positive are limited, asking students to engage in argumentation recognises that what students think and their reasoning are things which are both valued and valuable. It offers a means of transforming the deep grammar of pedagogy in school science and technology from one rooted in a view of it as a well-established body of knowledge to be transmitted to one in which science and technology are beliefs which must be justified by an appeal to evidence – a transformation which is long overdue.

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Chapter 63
Beyond Argument in Science: Science Education as Connected and Separate Knowing

Catherine Milne

In the past 15 years, more and more science educators have focused on a role for the *genre* of argumentation in scientific discourse and scientific literacy. According to Mikhail Bakhtin (Morris 1994), genres are stable 'typical forms of utterances'. Based on the complexity of cultural communication associated with specific fields, he differentiated between small everyday, primary genres used in everyday interactions and complex genres, such as argumentation associated with science. He argued: 'Many people who have excellent command of a language often feel quite helpless in certain spheres of communication precisely because they do not have a practical command of the generic forms used in the given spheres' (Morris 1994, p. 84). In its simplest form, an argument can be understood to be a connected series of statements intended to establish a position. Although there is general acceptance of the role of argumentation in science, and therefore of its importance to science education, how science educators believe argumentation should be incorporated into science education and the structure it should have, remain the basis of much discussion. Typically, there is acknowledgement of the limitations of a belief, commonly held by teachers, that science is about facts. Whilst increasing numbers of researchers are promoting argumentation and argument in science education to address this belief, there is less obvious support for a role for narratives or stories in knowing science. Like argument, narrative can be understood as a genre that in its simplest form is a text with a beginning, middle and end. However, as I hope to convince you in this chapter, *both* have a role in science education. My goal is not to create a false dichotomy between narrative and argumentation, but to show that, like argumentation, narrative has an educative role in science education.

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Locating Facts, Narrative and Argument in Science

Richard Duschl and Jonathan Osborne (2002) argue that a focus on facts privileges recall. More credit is given to students who can remember information about science than to student exploration of practices of science or of the relationship between facts and explanations in science. They make a strong argument for the role of argumentation in science education. In one respect, their discussion is ironic because the discourse genre of the scientific argument evolved from the seventeenth century attempts of experimental philosophers to convince their peers that the information that they had constructed was factual (Dear 1991). Peter Dear (1985) argues that, prior to the emergence in Europe of natural philosophy, the precursor of modern canonical science, the structure of argument based on general premises was held as superior to statements of fact based on observations of experiments. In previous centuries, authoritative texts laid down the accepted framework for discourse and interpretation based on rational argument. However, in the seventeenth century, the emergence of experimental philosophy placed at the centre of any knowledge claims discrete events and facts, which had been observed, providing evidence from the natural world for these claims. Barbara Shapiro (2000) argues that the concept of a fact originated from sixteenth century English law courts. In this context, people began to accept that humans could make just/true decisions based on events that were spatially and temporally distant from them. The concept of a fact was then generalised to other fields, including natural philosophy. Such analysis suggests that, historically, the relationship between facts and argument was very close in science but has been 'lost' in science education as teachers give priority to the recall of factual information.

Studies of the history of science bring to our awareness other facets of argument that have relevance for argument in science education. In their examination of the relationship between argument and seventeenth century science in England and France, Alan Gross et al. (2000) identify the emergence of *hedging* for indicating the quality of the evidence being presented to support knowledge claims. Hedging is common in the writing of modern scientists (Myers 1991). In structural analysis of argument described later in this chapter (e.g. Toulmin 1958) *qualifiers* might be thought of as performing a similar function, but I prefer the term, 'hedge'. From their study of seventeenth century science, Gross and colleagues also note the emergence of representations or inscriptions, such as diagrams, tables and graphs, which are visual devices for supporting a specific argument. They claim that early experimental philosophers, who were more interested in explaining than in just describing their observations, were more likely to develop 'robust arguments'. These arguments were based on plausible reconstructions of mechanical processes, like Robert Boyle's springy atoms, not visible to the scientist but necessary to *explain* the observed phenomenon. Such findings suggest that, when thinking about the structure and function of argument, we also need at least to acknowledge the role of *world-view* in the generation of theories used to explain observed facts. Additionally, social conventions and *politeness* were considered to be important aspects of the presentation of any argument, including scientific arguments. For example, in his seventeenth century writings, Robert Boyle attempted to convince his gentlemen peers that he had conducted an experiment and made the observations that he described whilst always treating his colleagues with respect. It was the argument that was important, not the person presenting it (Shapin and Schaffer 1985). These features remain characteristic of argument as it is used in science to make claims for the generation of new knowledge.

This brief examination of the nature of argument in seventeenth century England and France helps us to understand that scientific argument has a history and structure consistent with the evolution of modern canonical science. However, although many science education researchers seem to acknowledge and foster the value of *argument* and exposition for learning science, *narrative* has not been accorded the same status. But there is educational value in recognising narrative as an important discourse for learning science and also acknowledging its presence in contemporary arguments.

Argument, Narrative and Connected Knowing

In contrast with an argument, which involves someone in taking a position, a narrative can be described as a spoken or written text in which events about specific content are connected by time. Often the terms ‘narrative’ and ‘story’ are used interchangeably, thereby creating a belief that narratives lack the ‘truthfulness’ associated with facts. In the recent past of science education research, narrative has been associated with contributing to misconceptions. For example, critics of narrative activities (e.g. asking students to imagine they are cells, atoms or molecules) blame narrative for students’ desire to anthropomorphise (a bad thing) physical phenomena. However, more recently researchers found evidence that the use of stories actually assisted students to make sense of science (e.g. Bannister and Ryan 2001; Jegede and Okebukola 1991).

Indeed, scientists have written narratives that encourage an acknowledgement of the possibilities of narrative in science. Those that stand out include Primo Levi’s *The Periodic Table* (1984), which is really a series of short stories in which the personalities of various elements became metaphors for stages of Levi’s life. In one of the chapters called *Iron*, Levi explains to his friend and fellow student how the periodic table represents for him the highest form of poetry and in *Carbon*, he tells the story of a carbon atom through millennia as it moves via chemical processes from sedimentary rock to organic compounds. Another is James Watson’s *The Double Helix* (1980) in which Watson highlighted the human and unpredictable dimensions of scientific endeavour.

Fictional and non-fictional narratives are integral aspects of the human condition, which includes science. I argued (Milne 1998) for the storied nature of science, especially as science is commonly presented in science textbooks. From my analysis, I categorised four types of stories (heroic, discovery, declarative and politically correct science stories) used in textbooks to emphasise that the commonly accepted meanings and values associated with the cannon of science had become myths of school science. For example, *heroic science stories* were designed to represent specific scientists as courageous and determined uncoverers of the truth who transcended the limitations of their age and illuminated ages to come. One powerful example of these types of stories was the heroic portrayal of Galileo in his interaction with the Catholic Church where, according to a textbook narrative, he would not submit to their control when brought before the Inquisition. Commonly, embedded in these stories, is the belief that science is a more elevated form of knowledge than social or religious knowledge.

However, such analysis was limited. Although I provided strategies for critically analysing stories in order to identify the associated meanings and values of specific story types, and acknowledged the ubiquity of stories to human experience, my analysis did not acknowledge a central place for narrative in the learning of science. Since that time, my experience of analysing narratives in science textbooks and my involvement in developing and evaluating simulations for chemistry education have led me to acknowledge the importance of both narrative and argument for understanding science.

Narrative, Argument and Connected and Separate Knowing

Further support for this perspective comes from the work of Mary Belenky et al. (1997) in their landmark study of thinking in which they examined William Perry's claims of the developmental structure of cognition and ethics development in humans. Published in 1973, Perry's study evolved from Piagetian psychology and was based on analysis of middle-class White undergraduate males. Belenky and her colleagues set out to examine whether the proposed developmental structure for cognition and ethics found in young men was also relevant for women. In the process of interviewing many women about knowing and knowledge, they identified a strategy for generating knowledge, which they called *separate knowing*, which was associated with producing justified knowledge using evidence, rhetoric and argumentation. Argument is the genre of separate knowing.

At the same time, they identified a form of knowing that was far more common amongst young women than men, which they called *connected knowing*. Unlike separate knowing, for which the knower is separated from what is known so that both can be treated as objects, connected knowing, through the use of narrative, begins with the knower trying to understand another's position, seeking to understand what they are saying and refraining from argument. This means that each knower seeks actively to understand another's position without necessarily agreeing with that position. The goals of connected knowing are understanding and discovery and the goals of separate knowing are validation and evaluation (to be convincing or convinced). Learners need tools that allow them to be both separate and connected knowers. The role of science education should be to provide learners with access to these tools. A summary of the contrasts between separate and connected knowing is presented in Table 63.1.

Table 63.1 Contrasting features of connected and separate knowing (After Clinchy 1996)

Aspect	Connected knowing	Separate knowing
Goal	Understanding/meaning and discovery	Validation and evaluation, to be convinced or convincing
Relationships between knowers	Supportive	Persuasive and possibly adversarial
Relationships between knowers and what is known	Relational	Detached and objectifying
Emotions	Illuminate thought	Obscure thought
Ontology	Reality is personal	There is an external reality even if we do not know what it is
Authority (epistemology)	Personal experience	Mastery of knowledge
Genre	Narrative	Argument and explanation

Connected knowing values the search for connectedness between ideas, therefore supporting the need for networked understanding of ideas rather than isolated facts. Connected knowing is uncritical but not unthinking. Blythe Clinchy (1989) describes connected knowing as *imaginative attachment*, or trying to look at something from another's perspective and valuing the stories that they have to tell. Emotion and thinking are linked in connected knowing, a linkage that can be reinforced by asking questions that seek understanding, such as 'what does it mean?' and 'what in your experience led you to that?'.

My experience has been that both connected and separate knowing have salience to learning science but, when most science teachers and researchers think of coming to know in science, they think of separate knowing (the type of knowing associated with scientific argumentation). However, connected knowing and its genre of narrative is an equally powerful form of knowing that should also be included in our educational actions associated with learning science. Anat Zohar (2006) identifies connected knowing very closely with learning for understanding. She argues further that connected knowing constitutes a relativist position that accepts the possibility of multiple answers, whilst also accepting that not all answers are equally meaningful or valid. Jerome Bruner (1996) asks why science educators feel the need to devote so much effort to teaching the methods of science and rational thought whilst ignoring the narrative world in which we and our students live. Science education needs to see stories, not just as convenient ways of telling about science, but as central to the human condition. We need to find a place in science education for both the verisimilitude of narrative and the predictive and explanatory power of argument.

A Place for Narrative in Science Education

According to the semiotician, Roland Barthes (1978), narrative is a feature of all cultures and it is used within cultures as a mechanism for promoting learning. Hayden White (1981) argues that story is a 'metacode' because there is a meaning in the story that allows stories to be understood across cultures. Anthropological studies of narrative show that, across cultural groups, there is variation in the internal structure of narratives with respect to how characters and time are represented and why the narrative is told (Cortazzi 1993). However, consistently across the world, narratives are important and are imbued with purpose and value. Narratives provide people with strategies for connecting with their everyday lives and for organising experiences. Donald Polkinghorne (1988) describes narrative as the 'primary scheme by means of which human existence is rendered meaningful' (p. 11). Arthur Greasser, Murray Singer and Tom Trabasso (1994) argue for connection between narrative and everyday experiences, claiming that both narrative and everyday experiences involve people in performing actions in pursuit of goals, in overcoming any obstacles to these goals and in emotional reactions to events associated with goals and obstacles. Because human knowledge about these actions, goals, events and emotions is deeply embedded in our ways of being, we are likely to be more responsive to reading from a narrative text than expository one, such as the decontextualised text found in a textbook. In a previous study, Arthur Graesser (1981) showed that readers generated fewer inferences with expository text than with narrative. Such findings have implications for how educators construct learning experiences in contexts in which texts form a basis for teaching and learning.

Narrative and Language

Mikhail Bakhtin (1981) examined the relationship between canonical 'correct' language, which we often associate with the language of science, and conversational 'everyday' language that students bring to the science classroom. Both languages exist together in a mix, but they represent different ways of 'conceptualizing the world in words' (p. 292). In the science classroom, the accepted language is the canonical language of the science community. For many students, this language exists in conflict with the norms of everyday language with which they are more familiar. Learning science often involves students being required to adopt the argumentative features of science language to demonstrate their understanding of science (Lemke 1990). Jay Lemke argued that the distancing and certainty of scientific facts in the language of science used in science classrooms alienated students from their ill-defined everyday experiences. In some contexts, this conflict is described as a misconception possessed by students about science. For example, the vignette below is taken from a study of urban high school students learning about kinetic theory:

> [When] you have the liquid there, and you don't go to the boiling point, or you don't have heat on, [the molecules are] all stuck together but then, once it started boiling or heating up, it started spreading out. It's like running for their lives, saying "okay, I'm running! I'm leaving!" (Milne et al. 2011, p. 3)

This vignette could be interpreted as demonstrating the misconceptions that this student has about phase changes. For example, it is well known that molecules do not talk. However, Bakhtin helps us to think about these types of texts differently.

Traces of two or more discourses that can be identified in a narrative constitute *hybrid construction* (Bakhtin 1981). For Bakhtin, a hybrid construction belongs to a single speaker but contains within it 'two utterances, two speech manners, two styles, two "languages", two semantic and axiological belief systems' (p. 304). In the vignette, the student has incorporated two languages, namely, accepted science ('you have the liquid there') and everyday language ('it started spreading out') in her effort to communicate to others the sense that she is making of the phenomena that she observed.

Using hybridity theory, Elizabeth Moje et al. (2004) argue that narrative supports the creation of a third space in which people in a community draw on multiple funds of knowledge to make sense of the world and written texts. This third space or being 'in between' can be both liberating and constraining (Bhabha 1994). Kris Gutiérrez et al. (1997) describe a third space, in which changes in what counts as knowledge can take place. A third space is constructed from the merging of a first space of home, community and peers with a second space of the formal understandings associated with disciplines or institutions such as that experienced learning science. Homi Bhabha argued that narratives serve to identify roles and self. So narrative offers the possibility of providing a space in which students see a role for themselves in the learning of science.

Perry Klein (2006) acknowledges that practices in science education, which 'adhere closely to the relatively expressive features of human cognition and language', offer possibilities for human learning because they 'accommodate characteristics of human cognitive architecture and non-school language' (p. 30). Klein also argues that in young children, the capacity for using narrative structure develops earlier than the capacity to write information. He highlights how the move in science education to non-narrative forms raises the real possibility that students will find it difficult to connect with a discipline that is presented in genres lacking connection with the personal characteristics of narrative.

Understanding Narrative

Because narratives can be understood as 'symbolic presentation of a sequence of events that are connected by subject matter and related by time' (Scholes 1981, p. 205), without continuity of content or connectivity of time, we would have a list of events rather than a narrative. Sasha Barab et al. (2007) describe this aspect of a narrative as the *plot* that takes place in a *setting* where *characters* participate. The power of the plot is that it contextualises content so that facts can be transformed from things to be memorised to useful tools for addressing specific issues or questions. Additionally, narratives are purposeful. Their actions are motivated by goals, beliefs and desires (Norris et al. 2005).

For Jerome Bruner (1996), another broad characteristic of narratives is the presence of a level of *narrative expectancy* for the author and the reader. Readers can have two major responses to narratives based on whether the narrative follows routinised and well-rehearsed narrative structures, or if the authors do something unexpected such as breaching norms or deviate from conventions of structure and content. Because authors have the power to challenge readers to consider again what they took for granted, narrative expectancy requires the participation of both author and reader. In contrast to propositions that can be explained, narrative is a form of discourse that cannot be explained but can be *interpreted*. Thus, narratives provide a space in which readers with a broad range of different experiences can make sense of the narrative because it is open to question. Within a story, there is no empirical or rational strategy for identifying 'truth'. Interpretation is based on our experiences and values that influence the sense that we make of a narrative. Although many readers might assign causation and linearity to a narrative, there is no expectation that all readers will make the same interpretation.

Research suggests that humans organise events based on narratively structured thinking, and tend to unconsciously impose temporal and causal relationships on the logico-semantic structure of events (Herman 2003). Even for scientific knowledge, which is typically presented through arguments in which embedded empirical evidence supports specific models and theories, we seem to have a cognitive bias towards linear narrative in the construction of knowledge (Abbott 2003; Bruner 1986). For example, experimental reports typically begin with an introduction and a review of the known knowledge from which questions emerged to form the basis for study and end with a discussion or conclusion. Fredric Holmes (1987), in his examination of the relationship between scientific writing and scientific discovery, writes:

> [E]ven though the stylistic norms for modern scientific papers nearly preclude a direct narrative form of presentation, there are inevitably narrative *aspects* of a discussion of results, because such papers embody, as they have for three centuries, both a current argument for certain conclusions and a description of research that the author has carried on through a prior period of time. (p. 234)

Joan Solomon (2002), in her study of science stories, uses Mikhail Bakhtin's (1981) comparison of two genres, the epic and the novel, to develop an argument for the development of stories with which students can empathise. Bakhtin describes the epic as walled off from time: a space that is 'inaccessible to personal experience' and therefore not open to personal perspective or evaluation. Consistent with Catherine Milne's (1998) depiction of heroic science stories (i.e. epics in which scientists are represented as heroic figures), such structure removes them from the taken-for-granted aspects of everyday experience. As Solomon observed, stories that are presented in such an epic format are not likely to appeal to students because such stories do not support understanding through empathy. In his examination of the history of the novel, Bakhtin provides another insight when he highlights the power of humour in a novel to destroy epic distance and place characters in a 'zone of contact with the inconclusive events of the present (and consequently of the future)'. (Morris 1994, p. 183)

In summary, a narrative should have the following features:

Event Tokens

- Occurrences involve a protagonist in a place and time.
- Selection of tokens imbues narrative with meaning and value.

Author

- The author selects events for the telling.

Interaction

- The outcome of the interaction between the author and the reader is not determined.

Narrative expectation

- Each reader has an expectation about how the narrative should progress.
- Divergences from this can imbue the narrative with drama.
- Humour can bring the reader closer to the characters.

Regrettably, often narratives that are developed in science education for use as exemplars do not incorporate these features in their structure (see Norris et al. 2005 for examples of stories that are not stories) and therefore do not resonate with students (Solomon 2002).

What Narratives Bring to Learning Science

In science education, the use of narratives has been studied mainly in inquiry-oriented classroom settings where the narrative provides a context for problem solving, but is not central to the process of learning science (e.g. Cognition and Technology Group at Vanderbilt 1992). Some feminist researchers, such as Gaell Hildebrand (1998), advocate the use of 'hybrid imaginative genres' for learning science. For her, these hybrid genres consisted of a combination of scientific genres with imaginative or fictional genres. She recommended the use of alternative forms of writing including letters, poems, songs, scripts, advertising and journalistic structures. Whilst agreeing with Michael Halliday and James Martin (1993) and James Gee (2005) that students should have access to strategies that allow them to understand, use and deconstruct various genres associated with the practice of science, she argued for the need for pedagogical space for students to examine the construction of these genres. Consistent with the work of Belenky et al. (1997), she makes a claim for moving beyond the hegemony of accepted genres such as argument to use narrative in science education. Gee (2005) takes the position that everyday language and its narrative aspects do not prepare students to access the knowledge of academic disciplines. However, researchers such as Vaughn Prain and Brian Hand (1996) and Maria Varelas and her colleagues (2008), like Hildebrand, see a place for both types of genres in science learning. As Varelas et al. (2008) explain:

> [W]e believe that this is not an "either-or" issue. Learners need to be introduced to academic Discourse (language, ideas, ways of being, acting, and thinking) (Gee, 1991), but they need to use it in ways that allow them to bridge this Discourse with their lifeworld Discourse and everyday experience if they are to "own" science. (p. 67)

They argue that children's everyday language is not dangerous, but instead is an asset that should be used in the teaching and learning of science. Although Varelas and colleagues do not refer explicitly to narrative, others such as Polkinghorne (1988) have argued for narrative as the discourse by which people make sense of their experiences. Studies of work (e.g. Patriotta 2003) also have revealed the importance of narrative for sense making in organisations.

In an education context, narratives can be understood to provide specific functions: (1) conceptual links between students' experiential knowledge based on their daily experiences and the paradigmatic structural knowledge (based on the use of evidence for supporting scientific argument) (Kurth et al. 2002); (2) support for the creation of a third space for learning science (Moje et al. 2004); (3) semantic cues such as questions that capture students' attention at the beginning of inquiry to initiate an internal dialogue to further assist knowledge comprehension (Graesser 1981; Graesser et al. 1994); (4) support for connecting complex ideas and events by providing structures and sequences of phenomena under investigation (Bruner 1996); (5) support for student engagement through access to different writing tasks (Hildebrand 1996) and engagement in terms of a 'narrative appetite' (Norris et al. 2005); and (6) the discourse of connected knowing (Clinchy 1996). These are powerful educational reasons for valuing the use of narrative in the teaching and learning of science.

A Place for Argument and Explanation in Science Education

Over the past 10 years, there have been increasing calls in science education research for a focus on argumentation in science education as both an instructional strategy and a learning goal (Bricker and Bell 2008). These calls were largely initiated by recognition that a focus on learning facts in science did not prepare students well to participate in central epistemic practices of science: the ability to identify and evaluate arguments and to craft their own robust arguments using sources of evidence. Argument and explanation are seen as central to the justification and evaluation of knowledge claims in science and have been the focus of reform documents (AAAS 1993; Goodrum and Rennie 2007; NRC 1996).

The Value of Argument

In science, argument is important. Any report of a claim for new scientific knowledge through the conduct of an experiment published as a paper in a scientific journal constitutes a scientific argument. For scientists (usually there are teams of scientists involved), the goal is to convince their peers, so there is a rhetorical component to the framing of their argument. The process of constructing and condensing the plethora of observations that scientists have generated during their study into inscriptions, such as graphs, diagrams and tables, also has a rhetorical function (Roth and McGinn 1998). Michael Roth and Michelle McGinn's argument is consistent with that presented earlier by Gross et al. (2000) examining the historical evolution of argument in the seventeenth century. Because both the development of inscriptions and the associated argument are sociocultural acts, all members of a science community, from the novice to the expert, must learn to use these tools if they wish to be accepted as a member. If we want children and youth to understand how science is constructed, then it would seem to be educationally appropriate to provide them with opportunities in science education to learn about argument and to use argument. Arguments are important cognitively and philosophically. There have been proposals to align scientific literacy in its fundamental sense with developing a capacity for argument (Norris and Phillips 2003).

Rosalind Driver, Paul Newton and Jonathan Osborne identified a number of benefits for student learning including: (1) using argument through talk to support students' use of the language of science to represent the world in new ways; (2) understanding the role of argument in deciding the 'best' interpretation from data; (3) understanding the role of argument in theory choice; and (4) using argument to examine sociocultural issues that have a basis in science, such as the role of genetically engineered food or whether corn is an appropriate base material for biofuel. Whilst acknowledging the strength of the argument of Driver and colleagues, what is missing from this list of justifications for the place of argument in science education is recognition of the role of other factors in the decision-making process of science. Rarely is science decision-making exclusively or completely rational. For example, in his famous account of Watson and Crick's proposal for the structure of DNA, *The Double Helix*, Watson acknowledged the role of aesthetic criterion with his comment that 'the structure was too pretty not to be true' (1980, p. 124).

The Structure of Argument

Rather than using the historical development of scientific argument as a basis for developing an argument structure for use in science education, a number of educators turned to philosopher Stephen Toulmin's (1958) argumentation pattern (TAP). Toulmin developed his initial proposal for argumentation as an alternative to the increasingly restrictive tenets of formal logic. He acknowledged that argumentation was domain dependent, indicating the importance of context for meaningful argumentation and proposed a model consisting of numerous components including claims, grounds (evidence), warrant, backing (reasons supporting the warrant), rebuttals and qualifiers (limits of claim).

Using this pattern as an analytical tool for supporting and assessing students' ability to form and evaluate arguments, Thomas Russell (1983) was an early proponent of analysing dialogic interactions between teacher and students to assess whether claims are presented rationally and based on evidence or imposed authoritatively. Gregory Kelly, working with many colleagues on different studies, has used TAP as an analytic tool for identifying argument in student-to-student discourse in classrooms (e.g. Kelly et al. 1998) and for examining student writing (e.g. Kelly and Takao 2002).

In their study of knowledge integration using scaffolded multimedia learning environments, Phillip Bell and Marcia Linn (2000) used TAP for analysing student explanations based on structure and not on content. Driver, Newton and Osborne (2000) noted Toulmin's acknowledgement that, in order to make a claim for whether or not an argument is correct, domain-specific subject-matter knowledge needed to be incorporated into the development and evaluation of arguments. Jonathan Osborne et al. (2004) used the structure of TAP in professional education of teachers and accepted that such an 'argumentation template' (Ford 2008) needs to be used with care especially when the individual components are difficult to classify in individually generated arguments. Rather than using TAP, other researchers (e.g. Zohar and Nemet 2002) have acknowledged the role of content in the development of an argument, and identified strong and weak arguments through the analysis of type and number of justifications used in each argument.

I would prefer an analytical structure for argument that makes more use of analysis from studies of science practice, such as those by Greg Myers (1991), Alan Gross and colleagues (2000) and Peter Dear (1991), or that builds on the argument forms used by children as they play (Goodwin and Goodwin 1987). According to Marjorie and Charles Goodwin, their studies of a group of African American children aged 4–14 years in Philadelphia showed that legalistic argumentation, similar to that associated with Toulmin's TAP and with a he-said-she-said structure, was only observed between girls. However, they make the case for recognising the similarities of argumentation structure, especially reason-conclusion pairs, amongst children and for accepting that argument is a feature of children's lives, functioning socially to shape the behaviour of participants into coordinated action. Goodwin and Goodwin's studies of argument in children's lives suggests how we might begin to think about building on the argumentation experiences that children bring to the science classroom.

Challenges for Students with Using Argument and What Narrative Can Do to Help

Even though researchers are developing structures that can be used to support students' efforts at developing and using argument, studies continue to indicate that students struggle to formulate and support knowledge claims in science (e.g. Sadler 2004). Various theories have been proposed to explain why students find developing arguments and explanations so challenging. Possible explanations include that students are not developmentally ready (Sandoval and Millwood 2005), that students lack the domain knowledge necessary to make an argument (Keselman et al. 2004) and that the topics chosen for study have no connection to students' lives (Zohar and Nemet 2002). Anat Zohar and Flora Nemet (2002), Troy Sadler and Samantha Fowler (2006) and many other researchers used narrative scenarios to frame everyday and scientific dilemmas for which students were to develop arguments about how the dilemmas might be resolved.

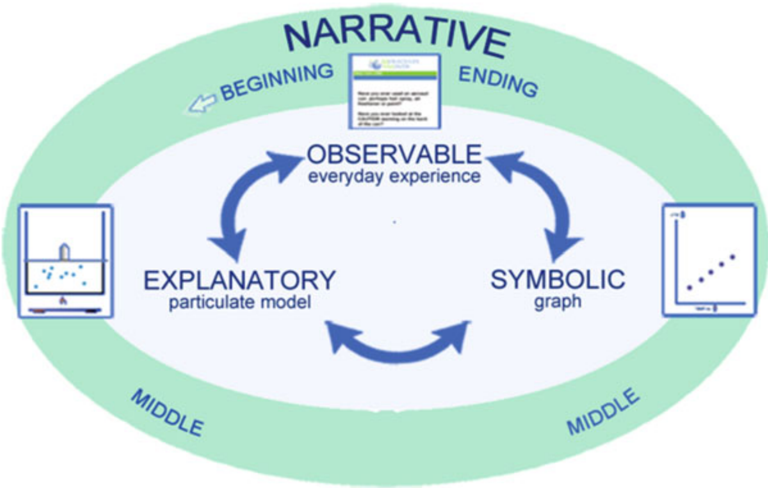

Fig. 63.1 Narrative structure with simulation and graph embedded (Ruth Schwartz, a doctoral student in the Molecules and Minds study, created this image)

Working with a research group called Molecules and Minds (M&M), we developed simulations in chemistry for students whose prior chemistry experiences had been very variable. After substituting introductory narratives into our simulations in place of the original case-study accounts, we found that students were more engaged using the simulation, worked with the simulation far longer than other groups and performed better on a transfer test in which students were asked to explain a real-life phenomenon (e.g. why a tyre is flat, how to prevent aerosol from exploding) using their knowledge of the gas laws (Milne et al. 2008). This suggested that connecting part of their everyday lives with the explanatory simulation in narratives communicated to students why it might be helpful for them to have some understanding of the explanatory frameworks central to understanding science. The introductory narrative served to provide a third space that brought together for the students, in a familiar context, an everyday phenomenon and questions that supported the use of explanatory frameworks from the academic discourse of chemistry.

In our multimedia simulations, the narrative provided the structure in which everyday phenomena involving a protagonist, the simulation and the graph were embedded (see Fig. 63.1). The narrative was intrinsic to understanding of the relationship between the phenomenon and the particulate explanation. With this narratively informed experience, students were then better able to develop explanations for other phenomena. For me, this is the profound outcome of this pilot study and it is worthy of further exploration; from their experience with narrative, students showed greater ability to transfer their knowledge.

It is surprising to me that there is not more discussion and research about the role of narrative in science education. I feel a connection with Hildebrand's claims about the hegemony of argumentation discourse/genre in science education as argument moves from being a discourse and genre of science, to being thought of as *the* metaphor for science. Like all genres, argument and narrative are constructions. But, if we focus most of our attention on argument, we lose sight of why it might be educationally valuable and ethical to include and foster narrative. Using narrative in the form of stories of experience provides another strategy for assisting students to make connections between their funds of knowledge and the science knowledge of the classroom. In science education, an exclusive focus on argument, which separates science from its social and cultural dimensions, serves to reinforce for students the exclusory nature of science (Roth 2005). The possibilities for hybridity offered through the use of narrative provide greater possibilities for students to see science as part of their lives and therefore a role for themselves in science. Educationally, I see a need for both connected and separate knowing in science education and a role for both argument and narrative.

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Chapter 64
Utilising Argumentation to Teach Nature of Science

Christine V. McDonald and Campbell J. McRobbie

Introduction

The development of informed views of the nature of science (NOS) is considered to be a pivotal goal of modern science education. Indeed, this important component of scientific literacy is emphasised within major reform documents across the world (e.g. American Association for the Advancement of Science [AAAS] 1990, 1993; National Research Council [NRC] 1996). A commonly utilised definition of NOS is provided by Norman Lederman (1992) as the epistemology of science, science as a way of knowing or the values and beliefs inherent to scientific knowledge and its development. Despite the extensive amount of research conducted in the field, the development of informed NOS views has been shown to be a difficult goal to achieve, with many studies reporting difficulties in changing learners' NOS views (Duschl 1990; Lederman 1992). Importantly, recent studies conducted by Foaud Abd-El-Khalick and Norman Lederman (2000) and Deborah Hanuscin, Valarie Akerson and Teddie Phillipson-Mower (2006) have highlighted the effectiveness of explicit NOS instructional approaches in improving learners' views of NOS. An explicit NOS instructional approach deliberately focuses learners' attention on various aspects of NOS during classroom instruction, discussion and questioning. This type of instructional approach is based on the assumption that NOS instruction should be planned for, and implemented in, the science classroom as a central component of learning, not as an auxiliary learning outcome. This approach is contrasted with

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implicit instructional approaches to teaching NOS which are underpinned by the view that an understanding of NOS will result from engaging students in inquiry-based activities, without the addition of deliberately focused (explicit) NOS instruction. Results from studies conducted by William Sandoval and Kathryn Morrison (2003) and David Moss, Eleanor Abrams and Judith Robb (2001) indicate that this type of instructional approach is generally not successful in developing learners' NOS views.

Although explicit instructional approaches have been shown to be relatively more successful than implicit instructional approaches in developing learners' NOS views, studies continue to show that the implementation of explicit NOS instructional approaches do not result in improved NOS views for all learners (e.g. Abd-El-Khalick and Akerson 2004). Emerging research in the field of argumentation has provided some evidence to suggest that an understanding of the processes of argumentation could aid the development of more informed understandings of NOS. This approach utilises instruction and/or engagement in argumentation in developing learners' views of NOS, and also could incorporate explicit NOS instruction. Research conducted in this area is relatively recent and is the focus of the present review. The next section outlines a rationale for incorporating argumentation in science education, as well as a brief overview of important recent studies in the field. This is followed by an examination of studies exploring NOS and argumentation, with the final section outlining some implications for science education.

Argumentation in Science Education

Argumentation in science education is a relatively new topic in the research literature, and comprehensive reviews of studies in this area have been conducted by Rosalind Driver, Paul Newton and Jonathan Osborne (2000) and more recently by Sibel Erduran and Maria Pilar Jimenez-Aleixandre (2007). This area of research has enjoyed considerable interest since the early 1990s with an ever-increasing number of studies being conducted in the field. In particular, research which has examined the use of argumentation as an instrument for interpreting and analysing discourse in science lessons has been a strong focus. The inclusion of argumentation in curricula is an important component of contemporary science education in many countries. Jimenez-Aleixandre and Erduran (2007, pp. 19–20) outline the rationale for the incorporation of argumentation in the science curriculum involves two factors:

> First, there is the need to educate for informed citizenship where science is related to its social, economic, cultural and political roots. Second, the reliance of science on evidence has been problematised and linked in the context of scientific processes such as investigations, inquiries and practical work. The advance of such efforts is a signal that science teaching needs to change to match the needs of citizens as well as scientists.

Various science educators have proposed that an understanding of argumentation contributes to scientific literacy. Russell Tytler (2007) states that the ability to make informed decisions about both personal and global issues is a key component of scientific literacy explicated in reform documents worldwide, thus emphasising the importance of engaging learners in argumentative practices. Engagement in argumentative practices provides learners with the ability to think scientifically about everyday issues and to critically analyse scientific reports (Newton et al. 1999); and argumentation strategies are recognised as a central tool for evaluating and justifying knowledge claims (Duschl et al. 1999). An appreciation of the argumentative nature of science enhances learners' understanding of the role of argument in constructing the link between data, claims and warrants (Osborne et al. 2004) and argumentation is a central component of both doing science and communicating scientific knowledge (Lemke 1990). Paul Newton and colleagues have proposed that argumentation is central to the philosophy of science, with knowledge being viewed as socially constructed. This knowledge emerges as a result of observation and argumentation, with the function of argument being to provide a link between the speculation of scientists and the evidence available (Newton et al. 1999).

The concept of argumentation utilised in the research literature is commonly associated with informal reasoning, the aim of which is 'to develop norms, criteria and procedures for interpreting, evaluating and constructing argumentation that are faithful to the complexities and uncertainties of everyday argumentation' (van Eemeren et al. 1997, p. 15). This form of reasoning often deals with ill-structured problems that have no clear solution and which require the application of inductive reasoning to solve. Precise definitions of the terms 'argument' and 'argumentation' do not exist in the literature, as a multitude of meanings are espoused by various scholars. A commonly utilised definition of argument is provided by Stephen Toulmin (1958) as an assertion and its accompanying justification. Jimenez-Alexiandre and Erduran (2007) support a dual meaning of the term argument from both an individual and social perspective. From an individual perspective, argument can refer to any item of reasoned discourse. Therefore, individuals who propose a perspective on an issue can be thought of as developing an argument. From a social perspective, an argument refers to 'a dispute or debate between people opposing each other with contrasting sides to an issue' (p. 12). Other scholars have conceptualised argument and argumentation in a different manner. Victor Sampson and Douglas Clark use the term argument to describe 'the artefacts students create to articulate and justify claims or explanations' and the term argumentation to describe 'the complex process of generating these artefacts' (Sampson and Clark 2008, p. 448).

An examination of previous argumentation studies conducted in the field of science education has highlighted the following general findings. First, most classrooms are teacher dominated, with students being given few opportunities to learn about, or engage in, argumentation (Cross and Price 1996). Second, factors such as age and previous knowledge can influence argumentation skills (Means and Voss 1996). Third, the relationship between conceptual knowledge and argumentation is complex and has been the focus of many current studies (e.g. Sadler and Fowler 2006). Fourth, students generally have poor argumentation skills, with specific difficulties such as ignoring data and warrants, introducing inferences and re-interpretations, jumping to conclusions and an inability to evaluate counter-evidence commonly reported

(Chinn and Brewer 1998). This final factor has been the impetus for many recent studies which have sought to improve learners' skills and/or quality of argumentation, and a general finding that has emerged from these studies is that explicit instruction in argumentation is a necessary prerequisite for enabling the development of learners' skills and/or quality of argumentation.

Explicit Argumentation Instruction

We define explicit argumentation instruction as the direct teaching of various aspects of argumentation including instruction pertaining to the various definitions, structure, function and application of arguments, and the criteria used to assess the validity of arguments. We also introduce the notion of supported argumentation instruction to describe an instructional approach to argumentation that does not explicitly guide learners in understanding the skills of argument, but instead provides prompts and suggestions for constructing arguments or evaluating evidence. Studies that have been conducted with software learning tools or within web-based environments often utilise this type of instructional approach.

Anat Zohar and Flora Nemet (2002), Randy Yerrick (2000) and Philip Bell and Marcia Linn (2000) reported that participants' skills and/or quality of argumentation improved over the course of interventions which incorporated explicit (or supported) argumentation instruction. In a similar vein, Maria Pilar Jiménez-Aleixandre et al. (2000) found that a lack of explicit instruction in argumentation resulted in no substantial improvement in students' skills of argument. Conversely, two studies (Jimenez-Aleixandre and Pereiro-Munoz 2002; Patronis et al. 1999) reported improvements in students' argumentation skills and/or quality in studies where neither explicit nor supported instruction in argumentation was provided. A closer analysis of these studies highlights an important trend. The studies which reported that explicit instruction improved learners' skills and/or quality of argument (or similarly found that a lack of explicit instruction hindered the development of learners' skills and/or quality of argument) were conducted in scientific contexts, and conversely the studies which reported that learners' skills and/or quality of argument were improved without the addition of explicit argumentation instruction were conducted in socio-scientific contexts. These findings suggest that there might be a relationship between the context of argumentation and the development of learners' skills and/or quality of argument.

The Importance of Context

Two contexts for argumentation in science have been highlighted in the science education literature by Jonathan Osborne et al. (2004), namely, scientific and socio-scientific contexts. Scientific contexts for argumentation are concerned with the application of scientific reasoning to enable an understanding of the justification for hypotheses, the validity and limitations of scientific evidence and the evaluation of competing models and theories (Giere 1979). The development of scientific argumentation is an important aspect of scientific literacy as these types of arguments 'expose the justification for belief in the scientific worldview and the underlying rationality that lies at the heart of science' (Osborne et al. 2004, p. 998). Current trends in the science education community towards improving scientific literacy also provide the impetus for studies which aim to develop and improve learners' argumentation in socio-scientific contexts. These contexts for argumentation are concerned with the application of scientific ideas and reasoning to an issue, and also invoke a consideration of moral, ethical and social concerns (Osborne et al. 2004). Alternatively, the term socio-scientific issues (SSIs) is commonly utilised in (2006) the science education literature to describe these contexts. Troy Sadler and Samantha Fowler describe SSIs as 'complex social dilemmas based on applications of scientific principles and practice' (p. 2). Developing learners' abilities to engage in arguments of this nature is deemed important as issues and controversies which are relevant to the real world of the student are able to be evaluated in this context.

Jonathon Osborne and colleagues' (2004) research which focused on enhancing the quality of teachers' and students' argumentation was the first empirical study identified in the literature to examine argumentation in both of these contexts (Osborne et al. 2004). This longitudinal study examined the implementation of a learning environment designed to support argumentation instruction in junior high schools by utilising explicit argumentation instruction. There was a modest improvement in the quality of students' argumentation. Also the level of argumentative discourse in scientific contexts was significantly lower than the level of argumentative discourse in socio-scientific contexts. The authors suggest that the initiation of argumentation in scientific contexts is more difficult for both students and their teacher, and a lack of conceptual knowledge can limit the ability of students and teachers to engage in argumentation on scientific topics, which often requires specific conceptual knowledge about the topic. Further, many students possess some understanding and knowledge about socio-scientific topics formed through their own life experiences, which could enable them to apply these concepts to their reasoning about socio-scientific issues.

Problems with Engagement in Argumentation

This review has begun to establish the importance of considering the context of argumentation and in incorporating explicit argumentation instruction (particularly in scientific contexts) to enable learners to develop their skills and/or quality of argumentation. Although some positive outcomes have been documented through implementing explicit argumentation instruction, results from some studies (e.g. Osborne et al. 2004) indicate that gains in argumentation skills and/or quality might only be modest, and learners might exhibit difficulties in applying this knowledge in differing contexts. In other words, learners could acquire skills of argumentation, such as supporting claims with evidence, providing warrants, considering alternatives and evaluating evidence, but still fail to engage or participate in argumentation. We propose that acquiring the skills of argumentation is a vital first step for learners involved in argumentation-based pedagogy. Developing the quality of learners' argumentation should also be emphasised. A critical third step is ensuring that learners engage in argumentation.

A number of factors have been found to influence learners' engagement in argumentation, such as the context of argumentation (e.g. Osborne et al. 2004), classroom culture (e.g. Kovalainen et al. 2002) and personal characteristics including a reluctance to criticise peers' ideas (e.g. Nussbaum et al. 2002). More recently, E. Michael Nussbaum et al. (2008) and William Sandoval and Kelli Millwood (2007) have proposed that learners' NOS views could influence their engagement in argumentation. The rationale for this view is based on the hypothesis that the difficulties which learners have in participating in argumentation could be explained by examining their epistemological views because, without developed epistemological views, learners might not realise that claims are open to challenge and refutation and require the support of empirical evidence (Sampson and Clark, 2006). Leema Kuhn and Brian Reiser (2006) assert that, if learners hold naïve views of scientific knowledge as a body of absolute facts, they are unlikely to see the need to engage in debates about scientific issues. This assertion was first proposed by Deanna Kuhn (1992) in her seminal work on argumentation. From her study of 160 participants' argumentation, she proposed that naïve epistemological views could influence people's engagement in argumentation, stating that people are unlikely to engage in argumentation if they do not appreciate its value. She highlights three epistemological orientations to which people could commit: absolutist, multiplist and evaluativist. An absolutist views knowledge as certain facts that are fixed and not subject to change. On the other hand, a multiplist views knowledge as personal opinions, all of which are equally valid, and thus not open to challenge. The most developed epistemological stance is characterised by evaluativists who view knowledge as evidence-based theories in which not all opinions are equally valid. Evaluativists carefully consider evidence and contrast this evidence with alternative viewpoints, using argument to verify claims. Taken together, this research indicates that improving learners' argumentation could involve developing their NOS views and designing and implementing pedagogical practices that support and promote argumentation in the classroom.

An examination of the literature revealed 12 studies which examined NOS and argumentation, and we have broadly categorised these studies into two lines of research. One line of research involves the influence of learners' NOS views on their argumentation, which we have already briefly discussed. As stated earlier, the impetus for studies in this area relates to problems with engaging learners in argumentation. A second line of research views the relationship between NOS and argumentation in a different manner. An assumption underpinning this line of research is that engaging learners in the process of argumentation could improve their understandings of NOS. Thus, this line of research explores the influence of argumentation on learners' NOS views, and therefore more specifically addresses the focus of our review. Before reviewing this line of research, we review studies which have examined the influence of NOS views on argumentation.

Influence of NOS Views on Argumentation

Studies which have examined the influence of learners' NOS views on their argumentation have been conducted in socio-scientific and scientific contexts. Research conducted in socio-scientific contexts has highlighted possible links between learners' NOS views and their engagement in argumentation. It is important to note that many studies conducted in socio-scientific contexts examine students' decision-making processes, and not necessarily their skills or quality of argumentation. Scholars working in this area posit that learners' views of NOS influence the manner in which they view, cite and use evidence that can support or oppose their pre-existing beliefs about particular socio-scientific issues. Research conducted in scientific contexts focuses on epistemology, inquiry and argumentation. Researchers working in this area propose that engaging learners in inquiry tasks such as constructing, developing, defending and evaluating scientific arguments and explanations, requires the application of epistemological understandings to support epistemic decisions.

Socio-Scientific Contexts

The ability to critically evaluate socio-scientific issues is considered to be an essential component of scientific literacy, and students need to learn about the methodological, social and institutional aspects of the scientific enterprise (Kolsto et al. 2006). The first empirical study of NOS and argumentation in a socio-scientific context was conducted by Dana Zeidler, Kimberly Walker, Wayne Ackett and Michael Simmons. The study was designed to investigate the relationship between students' views of NOS and their reactions to evidence that challenged their beliefs about a socio-scientific issue (Zeidler et al. 2002). Participants consisted of 82 students ranging from junior (years 9 and 10) high school science students to preservice elementary teachers. Data were collected from students' responses to questionnaires, written responses to a socio-scientific scenario on animal rights and interviews. Students received explicit instruction in neither NOS nor argumentation during the intervention. Data analysis indicated that, in a few cases, students' views of NOS were reflected in the arguments that they presented on a moral and ethical issue. Also many participants' responses were based on personal opinions and failed to integrate relevant scientific evidence, and participants' argumentation skills did not appear to improve as a result of investigating the socio-scientific issue (although these skills were not directly assessed). The authors recommend that teacher preparation programmes expose students to both explicit instruction about NOS and argumentation.

A similar study was conducted by Troy Sadler, William Chambers and Dana Zeidler who examined 84 high school biology students' views of NOS in response to a socio-scientific issue (Sadler et al. 2004). These researchers were interested in how students interpret and evaluate contradictory evidence when engaged in a global warming scenario. Students neither received explicit instruction in NOS or argumentation during the study, nor had their argumentation skills directly assessed. Students displayed an understanding of both the tentative and social NOS, although just under half of the students displayed naïve views of the empirical NOS. Because their views of the social NOS considerably influenced their reasoning and argumentation in the socio-scientific context, the authors recommend that explicit NOS instruction is necessary to ensure that students are provided with the opportunity to form developed views of NOS.

Kimberly Walker and Dana Zeidler (2004) also examined the role of NOS in decision making about a socio-scientific issue. The purpose of the study was to assess how a web-based instructional unit on genetically modified foods (GMFs) might elicit, reveal and develop 36 high school students' understanding of NOS, as well as informing their decision making. The study was designed to incorporate specific science content knowledge about GMFs, explicit NOS instruction and supported argumentation instruction in the form of guidance in the selection of evidence. Prior to the intervention, students completed a NOS questionnaire to assess their views of some aspects of NOS. No assessment was made of students' skills of argumentation prior to the intervention, although the authors note that none of the students had previous experience in formulating arguments or debating. At the conclusion of the intervention, student pairs took part in semi-structured interviews utilising questions from an open-ended NOS questionnaire (VNOS, Lederman et al. 2001) to assess their views of NOS. Findings indicated that students' views of NOS developed over the duration of the study were aligned with dynamic views of NOS at the conclusion of the study. Also NOS was not explicitly referred to in their arguments, although the issue-based activity did enable their views to be elicited and revealed. Because, in general, students were not able to develop sound, evidence-based arguments, the authors proposed that more time and explicit instruction in argumentation are necessary for developing students' abilities to construct sound arguments. They also recommended that teachers need to develop the necessary pedagogical skills to guide their students in effectively applying their NOS understandings to socio-scientific issues.

Conversely, a study which challenged the findings of the previous three studies was conducted by Randy Bell and Norman Lederman (2003), who also investigated the role of NOS in decision making about socio-scientific issues. The underlying rationale for the study was based on the premise that, if there is a relationship between NOS and decision making, then participants with diverse views of NOS are likely to exhibit different reasoning about socio-scientific issues. Twenty-one university professors and research scientists were purposively selected to provide divergent views of NOS, and were placed in two groups representing disparate views of NOS. Data sources included an open-ended NOS questionnaire (VNOS-B) which assessed their views of various aspects of NOS, an open-ended questionnaire designed to obtain information about their decision making in a variety of socio-scientific contexts, and individual interviews. The participants received explicit instruction in neither NOS nor argumentation, and their skills of argumentation weren't assessed. Results indicated that participants' NOS views were not a significant contributing factor in the decisions reached by the participants in either group, with reasoning patterns tending to focus on personal, social and political aspects of the issue. There was little reference to scientific evidence as a contributing factor in their reasoning. The authors recommended that learners need to be explicitly instructed in how to utilise and apply their NOS views when engaged in decision making on issues.

In summary, implications from the four studies reviewed in socio-scientific contexts highlight the importance of providing both explicit NOS instruction and explicit argumentation instruction to aid in the development of learners' skills and/or quality of argumentation, their NOS views and their engagement in argumentation. Mixed results were reported with respect to the influence of learners' NOS views on their reasoning, although it is important to note that recommendations stemming from these studies emphasise the importance of providing guidance to learners in applying their NOS understandings to socio-scientific issues. For example, learners who hold naïve views of NOS might not regard scientific content knowledge as an important aspect of their decision making when engaged in socio-scientific reasoning, and could misinterpret available data and claims to support their own pre-existing position on an issue. Thus, they might need to be provided with guidance in applying their NOS understandings during the decision-making process, and learn to critically evaluate scientific claims, some of which could oppose their pre-existing views.

Scientific Contexts

The first study identified in the literature into the influence of students' NOS views about scientific argumentation on their inquiry practices was conducted by William Sandoval and Kelli Millwood (2005). They investigated the quality of 87 high school biology students' written explanations about natural selection utilising a software tool designed to support scientific inquiry and guide students in constructing theory-based scientific explanations. Their research was guided by the assumption that implicit epistemological ideas are reflected in students' selection and use of data in their scientific explanations. Results indicated that the software tool successfully provided supported argumentation instruction via scaffolds that allowed students to construct logical arguments. Nevertheless, students had difficulties in citing sufficient data to support claims and also in providing warrants for some claims. Also many students viewed data as self-evident, and did not provide an explanation of the data in their scientific explanations. The authors proposed that students might not distinguish claims from data and might believe that data are an objective representation of scientific knowledge. Implications from this research suggest that students who display naïve views of NOS might not provide explanations or warrants for their claims, thus influencing their ability to engage in scientific argumentation effectively.

A more recent study conducted by the same authors examined 33 grade 7 students' ideas about how to warrant claims (Sandoval and Millwood 2007). They explored how students' argumentation practices developed during a 3-week unit on plant adaptation, and the possible influence of the inquiry on their ideas about NOS. Students completed the POSE (Perspectives on Scientific Epistemology; Abd-El-Khalick 2002) to assess their scientific epistemological views at the beginning of the study, which were found to be naïve. Supported argumentation instruction was provided during an online investigation in which students were instructed to present data-based arguments. Data analysis indicated that the majority of students were able to articulate claims, but that most students did not warrant their claims. During individual interviews, over half of the students cited that warrants were the reason for believing their claims, even though less than 25% of the students explicitly provided warrants in their written essays. The authors propose that the students might not have been motivated to provide explicit evidence (in the form of warrants) because the audience for the students' written arguments was their teacher and because their primary role was to provide the correct answer. Thus, the results of this study provide further empirical support for the assertion that learners' epistemological views influence their engagement in argumentation.

E. Michael Nussbaum and colleagues examined the influence of students' epistemic beliefs, and exposure to argumentation instruction, on the quality of their arguments (Nussbaum et al. 2008). Participants were 88 undergraduates (94% were seeking a teaching credential) randomly assigned to the treatment or control group, with only the treatment group receiving supported argumentation instruction. A web-based learning environment provided the context for the investigation, with both the control group and treatment group participants engaging in pair-based discussions of several physics problems. All participants completed a number of online surveys, including a survey assessing participants' tendency to approach or avoid arguments, and an epistemic beliefs survey. Participants were epistemologically classified as absolutists (12%), multiplists (28%) or evaluativists (55%). Results indicated that treatment group participants developed better-quality arguments than control group participants, and the authors propose that more direct instruction (i.e. explicit argumentation instruction) is likely to result in greater gains in argumentation. Another finding was that a significant proportion of treatment group participants expressed conceptually correct responses to one of the physics tasks.

Other results suggested that participants' epistemic orientations had several effects on their argumentation. Multiplists did not engage in argumentation as often as absolutists and evaluativists. They were not particularly critical of their arguments and they appeared to be neither aware of, nor worried by, inconsistencies in their reasoning. The authors state that this apparent tolerance for inconsistencies could be related to their epistemic orientation in which they believe that differing opinions can all be equally valid. In general, evaluativists (as compared with absolutists) brought up different ideas from their partners, rarely displayed inconsistent reasoning and tended to engage in more critical argumentation. Absolutists were more engaged in argumentation than multiplists, and the authors propose that their rationale for engaging in argumentation could be related to their epistemic orientation (i.e. they engage in argumentation to try to find the correct answer). Thus, findings from this study suggest the assertion that participants' epistemic orientations influence their engagement in argumentation, and that instruction in argumentation improves argument quality.

Recent research conducted by Lisa Kenyon and Brian Reiser outlines a functional approach to applying relevant epistemological understandings to the inquiry practices of 64 middle school students during an 8-week project-based unit on ecology (Kenyon and Reiser 2006). This approach to teaching NOS focused on encouraging students to use their epistemological views to guide their investigations whilst engaged in scientific inquiry tasks. A supported argumentation instructional approach was utilised using a software tool to examine data and to develop explanations and arguments. Students also received instruction in explicit argumentation during the study. Two design strategies were developed to support students' use of epistemologies in their inquiry tasks. The first design strategy was to use argumentation as a context for creating a need for students to apply their epistemological understandings to develop and evaluate scientific explanations. The second design strategy was developed to support students' conceptual understanding of the various parts of a scientific explanation. This framework was further enhanced by asking students to develop their own epistemological criteria to build and evaluate their scientific explanations. Using the set of student-developed epistemological criteria was found to facilitate engagement in argumentation and to help students to evaluate the quality of scientific explanations. The integration of classroom debates and argument allowed students to apply their epistemological criteria to guide and support their arguments. The functional approach to teaching about NOS developed in this study was relatively successful in allowing students to directly use and apply their epistemological understandings during scientific inquiry activities.

In summary, the four studies reviewed in this section provide some evidence to support the assertion that learners' views of NOS influence their engagement in scientific argumentation. In general, naïve epistemological views appear to constrain learners' engagement in scientific argumentation, whereas more informed epistemological views appear to promote engagement in scientific argumentation. The successful incorporation of pedagogical strategies which allow learners to recognise the relevance of their epistemological views to their reasoning is paramount to ensure that learners engage in argumentation effectively. Other findings suggest that argumentation instruction aided in the development of the quality of learners' argumentation in scientific contexts, thus underlining the importance of incorporating explicit instruction in argumentation when attempting to improve the quality of learners' argumentation.

Influence of Argumentation on Views of NOS

Four studies have been identified in the literature which have explored the influence of argumentation on views of NOS. Two studies were conducted in scientific contexts without incorporating explicit NOS instruction. The other two studies were conducted in historical, scientific and socio-scientific contexts, and incorporated explicit instruction in NOS and argumentation.

Early Studies in Scientific Contexts

Two studies conducted in scientific contexts provided initial support for the assertion that engaging learners in argumentation influences their views of NOS. Randy Yerrick (2000) investigated five low-achieving high school students' participation in a general science unit which focused on argument construction, question generation and experimental design. The researcher was interested in assessing changes in students' abilities to construct arguments within scientific contexts. He explicitly taught skills of argumentation to the students over an 18-month intervention that was implemented in an open-inquiry setting. No explicit instruction in NOS was implemented during the intervention. Results indicated that students' views of the tentative nature of scientific knowledge, the use of scientific evidence and the source of scientific authority developed over the duration of the study to become more closely aligned with informed views of these NOS aspects. The study supported the notion that engaging students in scientific argument and inquiry could lead to improvements in their views of some aspects of NOS, although this was not a specific aim of the study. Students' views of the above aspects of NOS were also reflected in their arguments, and some improvements in their skills of argument were also evident.

The second identified study was conducted by Philip Bell and Marcia Linn (2000) who assessed 172 middle-school students' argument constructions during a Knowledge Integration Environment (KIE) debate project. The study was guided by the assumption that arguments formulated by students reflect aspects of their views about NOS. Supported instruction in argumentation was implemented in the study via a software tool designed to make the structure of an argument visible to students. The tool also provided hints and prompts about various aspects of argumentation in order to guide students in developing and evaluating arguments from differing perspectives. No explicit instruction in NOS was implemented during the intervention, although students completed a multiple-choice survey about their views of NOS at the commencement and conclusion of the study. Students with more informed views of NOS created more complex arguments which integrated unique warrants, an increased frequency of warrant usage and more conceptual frames. Results also indicated that students' integration of knowledge and skills of argumentation improved over the duration of the study. The authors state that their study provides evidence for the claim that engaging students in the process of argumentation improves their understanding of NOS (based on participants' improvement in NOS understandings).

In summary, these two studies reported improvements in both participants' argumentation and their views of NOS. Both of these studies implemented explicit or supported argumentation instruction that has previously been shown to aid in developing participants' skills in and/or quality of argumentation in scientific contexts. Interestingly, although neither of these studies incorporated explicit NOS instruction, participants' views of NOS improved over the duration of the studies. These findings suggest that developing learners' NOS views might not require the integration of explicit NOS instruction in scientific contexts where explicit argumentation instruction is provided. As this assertion is contrary to a large body of research in the field of NOS that supports the notion that explicit NOS instruction is necessary to aid in developing learners' views of NOS, further studies are needed to provide empirical evidence to support or refute this claim.

Recent Studies

Meshach Ogunniyi (2006) evaluated the effectiveness of an argumentation-based, reflective course on the nature of science in terms of in-service science teachers' views of NOS. In contrast to the previous two studies conducted in scientific contexts, this study was situated in a historical context which emphasised the historical, philosophical and sociological aspects of science. Explicit instruction in NOS and argumentation were implemented in the course, which utilised argumentation as a reflective tool in developing valid views of NOS. Preliminary results were provided for three participants who were enrolled in a single-semester course that included instruction in the psychology and sociology of science and in the history and philosophy of science. A Nature of Science Questionnaire (NOSQ), interview schedules and reflective essays were utilised to assess teachers' understandings of NOS. Results indicated that teachers' views of NOS improved from a naïve view of science to a dynamic view of science. The author concluded that a major improvement in the teachers' views of NOS at the end of the course provided evidence of the effectiveness of a course which emphasises explicit argumentation instruction and consideration of historical, philosophical and sociological aspects of science. It is important to note that, because preliminary results only were reported in this study, care must be taken not to over-interpret these findings.

A recent study conducted by the first author, Christine McDonald, explored the influence of a science content course incorporating explicit NOS instruction and explicit argumentation instruction on five Australian preservice primary teachers' views of NOS (McDonald 2010). The course utilised both scientific and socio-scientific contexts for argumentation in order to provide opportunities for participants to apply their NOS understandings to their arguments. Data sources included questionnaires and surveys (VNOS-C, Abd-El-Khalick 1998; Global Warming Survey, Sadler et al. 2004; Superconductors Survey, Leach et al. 2000), interviews, audiotaped and videotaped class sessions and written artefacts. Results indicated that the science content course was effective in terms of four of the five participants' improved views of NOS. A critical analysis of the effectiveness of the various course components implemented in the study led to the identification of contextual, task-specific and personal factors that mediated the development of participants' NOS views. Regarding contextual factors, engaging in argumentation in scientific contexts was more difficult for participants than engaging in argumentation in socio-scientific contexts. A lack of provision of specific scientific content knowledge hindered participants' engagement in argumentation in some scientific contexts. Other findings suggested that participants did not recognise a need to explain their data in some scientific contexts. In addition, engaging in oral argumentation presented challenges for some participants because of a perceived lack of scientific content knowledge, insufficient skills of oral argumentation and the group dynamics present in the classroom.

Task-specific factors, such as the inclusion of argumentation scaffolds, facilitated participants' engagement in argumentation in some socio-scientific contexts and, conversely, a lack of consideration of alternative data and explanations hindered participants' engagement in argumentation in some scientific contexts. The inclusion of epistemological probes was found to help in the development of participants' views of NOS. Used in conjunction with explicit NOS instruction, these written or verbal prompts were successful in orienting participants' attention to relevant NOS aspects highlighted in a task and/or in focusing participants' attention on a question designed to draw on their epistemological knowledge or reasoning. The lack of epistemological probes in some tasks hindered participants' abilities to apply their views of NOS to their reasoning during argumentation.

Personal factors, such as perceived previous knowledge, a lack of appreciation of the importance and utility value of learning about NOS and the durability and persistence of pre-existing beliefs, also hindered the development of participants' NOS views. Results indicated that participants who claimed that they already knew about NOS did not have as much incentive to be receptive to learning more about NOS, as they did not initially recognise a need to change their pre-existing views. Other results indicated that the participant who didn't recognise the importance of developing informed understandings of NOS was not motivated to change his pre-existing views of NOS. The influence of this participant's considerable background life experience was found to limit his ability to discard his previously unchallenged and largely naïve views of NOS. This study provided evidence to support the inclusion of explicit instruction in NOS and argumentation as a context for improving learners' NOS views and to highlight the myriad of factors which could impact on the development of learners' views of NOS and their engagement in argumentation.

Implications from these two recent studies highlight the effectiveness of incorporating explicit instruction in both NOS and argumentation in attempts to improve learners' views of NOS. These findings suggest that simply engaging learners in argumentation might not be sufficient to ensure their NOS views are developed. Explicit attention to specific NOS aspects incorporated at appropriate intervals during argumentation-based interventions could provide cognitive anchor points which allow learners to access and engage in epistemological discourse during argumentation. We contend that a conscious awareness of the various aspects of NOS is needed for learners to apply their epistemological views to their arguments. Explicit NOS instruction and guidance in applying NOS understandings is imperative to fulfil this role.

Implications for Science Education

The quest for the achievement of informed views of NOS for all learners continues to inspire science educators to seek effective instructional interventions that aid the development of learners' NOS views. Can engaging learners in argumentation lead to improvements in their NOS views? This review sought to provide an answer to this question by examining studies which have explored NOS and argumentation in science education. We categorised these studies into two lines of research: studies exploring the influence of learners' NOS views on their argumentation and studies exploring the influence of argumentation on learners' NOS views. Findings from the first line of research indicate that (a) learners' NOS views influence their engagement in argumentation in scientific contexts (mixed findings reported in socio-scientific contexts), (b) the provision of explicit instruction in NOS and argumentation is recommended for the development of learners' skills in and/or quality of argumentation, their NOS views and their engagement in argumentation and (c) guidance is needed to ensure that learners recognise the relevance and application of NOS views to their arguments via appropriate pedagogical strategies. Findings from the second line of research indicate that (a) engaging learners in scientific argumentation can improve their NOS views *without* the addition of explicit NOS instruction, (b) engaging learners in explicit instruction in argumentation *and* NOS leads to improvements in their NOS views and (c) a myriad of factors can influence learners' engagement in argumentation and development of NOS views.

Taken together, these findings provide some evidence to support the claim that engaging learners in argumentation leads to improvements in their views of NOS. Importantly, two qualifiers are needed to support this claim. First, there is a lack of empirical evidence that explicit argumentation instruction alone is sufficient for improving learners' views of NOS. Although two reviewed studies in scientific contexts (Bell and Linn 2000; Yerrick 2000) reported improvements in participants' NOS views without the addition of explicit NOS instruction, the majority of studies reviewed support the incorporation of explicit NOS instruction in addition to explicit argumentation instruction in interventions that aim to develop learners' views of NOS. As stated earlier, we believe that a conscious awareness of relevant NOS aspects is necessary for enabling learners to apply their epistemological views to their arguments. Learners must also be provided with guidance in applying these views to their arguments via appropriate pedagogical strategies.

Second, a variety of factors have been found to mediate learners' views of NOS and their engagement in argumentation (McDonald 2010). These findings suggest that the intersection between the development of NOS understandings and engagement in argumentation is complex and subject to a number of competing influences. For example, the design of classroom tasks needs to be carefully considered to ensure that these tasks incorporate appropriate epistemological scaffolding via explicit NOS instruction and the inclusion of epistemological probes. The incorporation of argumentation scaffolds and the provision of alternative data and explanations are also necessary for promoting engagement in argumentation. Contextual factors such as the mode of argumentation (oral or written) need to be considered in order to ensure that learners are able to engage in argumentation effectively. The provision of specific content knowledge could also be required in scientific contexts to support the development of scientific argumentation. Finally, personal factors, such as perceived previous knowledge about NOS, appreciation of the importance and utility value of NOS and the durability and persistence of pre-existing beliefs, must be considered imperative as these attributes can be paramount in influencing the development of some learners' NOS views.

We believe that using argumentation-based instructional approaches which incorporate explicit instruction in NOS shows promise as an effective avenue for developing learners' NOS views. Intuitively, more empirical research is needed in this area to add to the emerging body of knowledge about NOS and argumentation. The central role of NOS and argumentation in the attainment of scientific literacy for all learners further highlights the importance of future research efforts in this area.

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Chapter 65
Teacher Explanations

David Geelan

Science teachers' explanatory frameworks – the ways in which they use analogy, metaphor, examples, axioms and concepts and these elements are tied together into a coherent whole – are an increasing focus of interest in science education research. This chapter reviews some of the literature generated as a result of that interest.

There is, however, a surprisingly small amount of existing research literature in relation to what would seem to be a central topic in science education. A search of the ERIC clearinghouse of educational research with the term 'science teach* explain*' yields 1362 hits, but the majority of these focus on student explanations (e.g. Margaretha Ebbers and Pat Rowell 2002) and other issues such as students' generation of analogies (e.g. David Wong 1993a) rather than teacher explanations. Fewer than 35 papers focus in some way on the issues of teacher explanations in science. Some of the work on student explanations is tied in with the growing emphasis on argumentation in science education.

This dearth of research on teacher explanations in part could be because a strong and welcome emphasis on student learning – including constructivist, constructionist and enactivist perspectives – in recent science education research has shifted attention away from the actions and activities of teachers. One purpose of this chapter, however, is to suggest that teacher explanations are not necessarily antithetical to inquiry learning or tied to lecturing, and that teacher explanations are a fruitful field for further research.

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Types of Explanation

Much of the research reported here focuses on verbal explanations given *by* teachers *to* students, often in a lecture-like or demonstration context. David Treagust and Alan Harrison (2000a, b) analysed Richard Feynman's (1994) lectures on physics in exploring the features of explanations, and Zoubeida Dagher and George Cossman (1992) focused on teachers' verbal explanations.

These are not the only kinds of explanations that are given in classrooms, of course. Explanations are often collaboratively generated as part of class discussions, constructed from fragments offered and examined by students and teachers. Students explain scientific ideas to other students (e.g. Lyn Dawes 2004), and this too is an important avenue for developing understanding on the part of both the explainer and the receiver of the explanation.

Teachers also use diagrams and demonstrations to illustrate their verbal explanations, and it could be argued that a proper analysis of the explanation needs to include the whole 'verbal+visual' situation. There is increasing research interest in studying the use of 'scientific visualisations' – computer-based animations and simulations – in science education. John Gilbert et al. (2008) have collected and analysed much of this research, and it can be argued that the use of visualisations falls within the more general discussion of science teaching explanations.

Features of Explanations

David Treagust and Allan Harrison (1999) discussed the issue of explanations in science and science teaching. They noted that secondary school students often confuse explanation with description (Horwood 1988) and drew on David-Hillel Ruben's (1990) work on the philosophy of explanations in discussing explanatory frameworks. Treagust and Harrison note that:

- There are important philosophical and epistemological differences between science explanations and science teaching explanations.
- Science explanations are strictly characterised as theory and evidence-driven, use correct scientific terminology and can include analogical models.
- Science teaching explanations differ in rigour, length and detail, involve varying degrees of 'explain how' and 'explain why', are sometimes open-ended, include human agency and can raise new questions as they answer previous questions.

Strasser (1985) draws a distinction between 'explanation', which he identifies as the mode of the natural sciences, and 'understanding', which he identifies with the 'human sciences', hermeneutics and phenomenology. This distinction is useful in discussing the differences between science explanations, which are law-like, highly generalised and rigidly logical, and science teaching explanations, which can be more fluid and can draw on analogy, anthropomorphism and teleology in order to connect with students' prior understandings and life contexts.

Ruben's (1990) book *Explanation* is in the field of academic philosophy and, although it is interesting and illuminating, it rapidly moves too far into the technical language and esoteric concerns of that discipline to be of direct use to the field of science education.

Judith Edgington (1997) asks 'What constitutes a scientific explanation?' She notes that philosophers, scientists and science educators are all interested in this question, but that each group focuses on different facets of the issue and has different perspectives and concerns. She reviews the literature on explanation in science education, and notes that there is little past research on these issues and considerable potential for future research to be conducted.

Studies of Science Teacher Explanations

The papers briefly discussed above are largely philosophical explorations of the concept of explanation in general and in its application to science education, along with attempts to systematically lay out some of the issues around science teaching explanations. Papers reviewed in this section are more direct research studies of actual explanations offered by teachers to students in classrooms.

Science Disciplines and Levels of Education

Of the 24 studies reviewed here, two are specifically in the field of biology education, eight in physics and five in chemistry. Only one is in the field of earth science. One paper is in elementary science education and another in middle school, whilst six are in high school contexts. The remaining papers identify no specific science discipline and pertain to teacher education or other domains and levels of education.

Types of Teacher Explanation

Dagher and Cossman (1992) observed and audiotaped the science classes of 20 high school teachers and analysed the transcripts using a constant comparative method. They identified 10 different classes of explanations, which they described as analogical, anthropomorphic, functional, genetic, mechanical, metaphysical, practical, rational, tautological and teleological. There is not enough space here to explore all of these different types of explanations individually, but attention has been paid elsewhere in the literature reviewed to the use of analogy, anthropomorphism and teleology in explanation, as well as to avoiding tautology in explanation.

Explanation and Technology

A number of studies have explored issues arising when explanations are given in contexts other than face-to-face, including in web-based teaching and even in situations where the computer itself is developing and delivering explanations.

Daniel Suthers (1991) surveyed a variety of artificial intelligence techniques used for generating explanations for teaching purposes and developed a computer programme – PEG, an acronym for Pedagogical Explanation Generator – that was able to draw on a data set in the physical sciences to provide explanations for students. Whilst we might harbour some doubts about the ability of computer-based explanations to ever supplant human abilities to create, tailor to the context and situation and adapt explanations, Suthers does not claim that that outcome is possible or even desirable. Rather, he suggests that the automated explanations are one ‘explanatory resource’ amongst many available to students. In many ways, the most interesting feature of this paper is the discussion of the different approaches that have been used in the attempt to allow computers to construct explanations, because it seems plausible at least that these might be analogous to some of the strategies that human explainers use when developing explanations.

Shawn Glynn et al. (2007) explored the use of analogies as explanations in web-based science education contexts. Their paper outlines what analogies are and how they are used in explanation, as well as exploring science teachers’ use of analogies. It offers some exemplars of good web-based explanations, as well as guidelines for constructing new analogical explanations on the web.

Victor Sampson and Douglas Clark (2007) describe an online teaching strategy that they describe as ‘personally seeded discussion’ (i.e. intended to group students into small discussion clusters based on their responses and modes of scientific reasoning). In particular, the software groups students on the basis of their *different* explanations for a particular phenomenon and then asks them to seek consensus. The discussions are focused on helping students to develop a strong understanding of how scientific knowledge is generated, justified and contested and to involve them in scientific argumentation. This work uses teacher explanations both as teachers participate in online discussions and implicitly in the materials developed, and teacher explanations serve as models for students as they learn to explain and argue for their scientific ideas.

Zacharias C. Zacharia (2005) investigated the effect of interactive computer simulations of scientific phenomena on the nature and quality of the explanations offered by science teachers in a postgraduate course on physics content for practising teachers. Zacharia used the Predict-Observe-Explain sequence with the teachers in relation to both the computer-based simulations and more traditional textbook-based assignments on the content, and found that, when the teachers interacted with the computer-based simulations, the explanations that they constructed were richer, more detailed, scientifically more accurate and involved more formal reasoning. This work obviously has implications for science teacher education as well as for the use of technology.

Analogy

Significant research attention has been paid to the use of analogies in teaching science – this work forms the largest single body of literature in relation to explanation in science education.

Paul Thagard (1992) applied a theory about how analogies are used in thinking to the pedagogical use of instruction. The theory is focused on viewing analogies as the 'satisfaction of multiple constraints'. Thagard's theoretical perspective explores approaches to explaining why good analogies are good and bad analogies are bad, in terms of the pragmatic, semantic and structural constraints that form their context. His scheme for judging the quality of analogies, like schemes for judging other kinds of explanations, is valuable in science education and has not yet been sufficiently operationalised into a programme of research.

David Wong (1993b) asked 11 students who were training to be secondary school science teachers to generate explanations for a piston-and-cylinder device and noted features of the analogies that they generated in this situation where knowledge was being generated from fragmented, incomplete prior knowledge rather than from a well-organised and well-understood field of knowledge. Wong summarises his findings as follows:

> The results provide empirical support for the generative properties of analogies; that is, analogies can stimulate new inferences and insight. Furthermore, under specific conditions, individuals can productively harness the generative capacity of their own analogies to advance their conceptual understanding of scientific phenomena. (p. 1259)

Samson Nashon (2004) recorded the kinds of analogies used by three Kenyan Grade 10 physics teachers. He determined that many of the analogies used were connected to the students' life worlds – Nashon uses the term 'environmental' – whilst a number were also anthropomorphic in nature. Nashon prefers teachers to use what he identifies as 'scientific' analogies, in which both the target concept and the analogy fall within the domain of scientific knowledge. However, it could be argued that analogies that use features of the students' own life experience to help them to understand the target scientific concepts might be valuable both in enhancing understanding and in keeping students interested in science. Nashon also notes that careless or unskilled use of analogies can lead to misconceptions, and to students carrying misunderstandings about the analogue across to the target concept. He suggests that teachers should plan their use of analogies carefully and explore with students their understanding of the analogue and the analogy in order to ensure that their understanding of the target concept is as robust and scientifically accurate as possible.

David Brown and John Clement (1989) suggest that much research on analogies in science education focuses on situations in which students do not have any knowledge or understanding of the target concept. By contrast, they explored the situation in which students already believed that they understood the target concept. They note that, in this situation, it is conceptual change in Posner et al.'s (1982) terminology, rather than conceptual development, which is the goal of the instruction using analogies. In conducting four case studies of tutoring interviews, Brown and Clement identified four factors important for success in using analogies to overcome misconceptions:

1. A useful anchoring conception
2. Explicit development of the analogical connections between an anchoring example and the target situation
3. Interactive engagement and dialogue about the analogy with the student, rather than simply presenting it in a text or lecture
4. The student's active construction of a new explanatory model of the target situation

Rodney Thiele and David Treagust (1994) examined the ways in which four chemistry teachers used analogies to explain concepts. They identified the types of analogies used, and if they were used well or less well, and explored the implications of using case studies similar to this one in teacher education to teach trainee teachers how to use analogies skilfully.

Noah Podolefsky and Noah Finkelstein (2007) offer an approach for building frameworks of linked analogies to scaffold student learning in physics, particularly the learning of difficult, abstract concepts. They compared the results of a comparison of the approach that they advocate with a non-analogical approach to teaching the same concepts, and showed significant advantages of their approach for students' conceptual learning.

Multiple Representations in Chemistry Education

There is not enough space in this chapter to explore all the ways in which verbal and written explanations have been complemented by visual and tactile representations, or to explore the ways in which teachers use explanations in parallel with experiments and demonstrations. There is value, however, in looking specifically at the issue of multiple modes of representation in chemistry education. The key feature of many or most explanations in chemistry is the way in which properties and processes at the atomic and molecular levels are the causal explanations for the changes observed at the macroscopic level, and the way in which these processes are represented symbolically using diagrams and chemical equations.

Austin Hitt and Jeffrey Townsend (2004) suggest that students struggle to understand chemistry concepts because they do not have direct sensory access to phenomena at the atomic and molecular levels, and struggle to translate their developing chemical knowledge across the microscopic, macroscopic and symbolic levels of meaning. Hitt and Townsend describe modelling clay with students in order to explore the molecular world and construct explanations for chemical phenomena, and they claim that this approach has significant potential for enhancing students' understanding.

David Treagust et al. (2003) also take up the issue of chemistry explanations and multiple levels of representation. They explored students' instrumental and relational understanding of chemistry concepts after instruction in a Grade 11 chemistry class using analogies and a variety of other forms of explanation. The paper uses examples of teacher and student dialogue to demonstrate the ways in which both symbolic and submicroscopic (molecular level) representations are used in explanations. The study suggests that both levels of explanation are important to developing good understanding in chemistry. Treagust et al. also report that the meanings ascribed to particular representations by students do not always mirror those intended by the teacher.

Anthropomorphism and Teleology

In a number of papers, the roles of various features of everyday explanations that are usually considered inappropriate in scientific explanations were considered along with the influence of these kinds of explanations in science teaching. Treagust and Harrison (1999) suggested that anthropomorphism and teleology might in fact be valuable features of science teaching explanations if used judiciously.

As far back as 1979, Ehud Jungwirth (1979) was exploring biology teachers' use of anthropomorphic (ascribing human attributes and motivations to scientific objects and processes) and teleological (implying that scientific processes are purposeful) explanations. In particular, Jungwirth focused on whether the students were able to 'see through' such explanations in order to understand the correct scientific explanations for the phenomena, or whether they accepted the teachers' anthropomorphic and teleological explanations as factual.

Maria Kallery and Dimitris Psillos (2004) interviewed Greek teachers of junior elementary students and asked the teachers to complete written tasks in relation to the issue of anthropomorphic and animist (scientific objects and processes being described as though they were living things) explanations. The teachers expressed the view that using these types of explanations can be cognitively – and, in the case of some animist explanations, emotionally – harmful to young students. At the same time, however, Kallery and Psillos observed that the teachers did use anthropomorphic and animist explanations in their teaching. The participating teachers ascribed this to their low levels of content knowledge and pedagogical content knowledge in science.

Vicente Talanquer (2007) explored the use of teleological explanations in chemistry textbooks and concluded that such explanations are used, and that they sometimes can be valuable pedagogically as a means of helping students to understand the energetically 'preferred' direction of particular reactions. He also suggested that, where teleological explanations are not used carefully and the underlying laws governing the behaviour of the system elucidated for students, this form of explanation can lead to students developing misconceptions about the phenomena or overgeneralising the explanation.

Dagher and Cossman (1992) also identified 'tautological' explanations in their study of teachers' classroom explanations, giving as an example 'Chromosomes are in pairs so that they can pair' (p. 366). Ehud Jungwirth (1986) reviewed three studies addressing the problem of tautological explanations – explanations which manipulate the pieces of the thing to be explained without adding any new information or clarity – and reported an intervention programme with practising teachers that showed that they could be taught to avoid offering tautological explanations.

Teacher Education, Teacher Knowledge and Teaching Explanation

Several studies explored issues related to teacher knowledge and teacher explanations, including the explanations constructed by beginning teachers. Other papers considered the ways in which scientists explain ideas and compare those explanations with science teaching explanations, or describe criteria for judging the quality of explanations.

Alan Goodwin (1995) studied the explanations given by both science textbooks and beginning teachers who were graduates of science degrees. He found that both classes of explanations included logical flaws, as well as errors of scientific fact, and noted that it is important for students to be able to critically examine the explanations offered to them. Whilst I would agree that this is an important skill, it is one that needs to be developed throughout a student's scientific learning journey. Therefore, it is still important to seek to improve the quality of the explanations given by teachers and textbooks so that students can develop appropriate scientific knowledge.

Thomas Russell (1973) explored the messages about the nature of authority that were implicit in teachers' scientific explanations and arguments. He described a scheme for categorising arguments and identifying the hidden views about the nature of authority – essentially, the distinction between students accepting ideas based on the authority and position of the teacher or on the basis of the 'warrants' or forms of evidence from within the discipline that are advanced to support it – that played themselves out in three 'teaching incidents' which are described and analysed in the paper.

George Brown and John Daines (1981) elicited the opinions of 93 lecturers on the question of whether explaining is a skill that can be learned (or, presumably, something innate). In general, the respondents felt that most of the 40 listed elements of explaining *could* be learned, to varying degrees. Brown and Daines found that there were significant differences between the views of science and arts lecturers, but little difference between the views of relative neophytes and more experienced academics. They suggested that these views could have arisen from the ways in which the lecturers had experienced lecturing and explanation as students themselves. Their work has been influential since it was published and is frequently cited in adult education and higher education contexts.

Laurinda Leite et al. (2007) explored the explanations given for phenomena in the liquid state by teachers and prospective teachers in Portugal, Spain and Italy. They found that the explanations given by both groups in all three countries were poor (i.e. did not correspond with a correct scientific understanding of the phenomena), although the in-service teachers displayed fewer misconceptions than their preservice colleagues. The authors suggest more explicit attention to liquid-state concepts in science preparation, implying that they believe the problem is with the teachers' content knowledge in this field rather than with their skills in explaining the concepts to students.

This is a distinction that is sometimes found in the literature: If students are having difficulty understanding teacher explanations, or if the explanations offered are of poor quality, is the problem with the teacher's knowledge of the relevant scientific concepts, or with his/her skill in constructing explanations? Some ingenious research to address this issue would make an important contribution to the literature of teacher explanations in science.

Katherine McNeill and Joseph Krajcik (2008) focused on the activities of teachers who were explicitly teaching their students how to construct scientific explanations. Thirteen teachers working with 1,197 grade 7 students in a project-based chemistry unit were videotaped as they introduced the idea of scientific explanations to their students through modelling, making the rationale for explanations explicit, defining explanation and connecting scientific explanation to everyday explanation. McNeill and Krajcik found that different teachers used different instructional strategies in introducing this concept, and that these differing strategies led to differing results in terms of students' understanding of scientific explanation.

Combining Information in Explanations

Richard Mayer and Joshua Jackson (2005) conducted an experiment in which two groups of students were given a booklet containing text and illustrations that provided a qualitative explanation of the phenomenon of the formation and movement of ocean waves. One of the two groups had this information supplemented in an expanded form of the booklet with some further illustrations and some quantitative equations for the phenomenon being explained. Mayer and Jackson found that the students presented with the quantitative information developed much weaker qualitative understandings of the relevant phenomena than did the students who were given only the qualitative information. This suggests that the order and organisation of the various elements of an explanation are important to learning.

Judging the Quality of Teacher Explanations

Stephen Norris et al. (2005) explored the use of 'narrative explanations' in science education and developed a theoretical framework for categorising and conducting research into such explanations. Their discussion explores questions of the nature of narrative and of explanation, and offers criteria for judging the effectiveness of narrative explanations in science education.

Hannah Sevian and Lisa Gonsalves (2008) developed a rubric for judging the quality of scientific explanations. Although it was initially developed for the explanations given by science graduate students who were moving into science teaching roles within universities, Sevian and Gonsalves suggest that it can be of value for 'evaluating, or self-evaluating, science explanations by science professors and researchers, graduate students preparing to be scientists, science teachers and preservice teachers, as well as students who are explaining science as part of learning' (p. 1441). Sevian and Gonsalves claim that, because their rubric separates the content knowledge and pedagogical knowledge elements of teachers' science explanations, it offers significant research potential for distinguishing (and remediating) flaws in teacher explanations that are due to poor content knowledge from those due to poor explaining skills.

Future Research

A variety of different approaches has been used in conducting research on teacher explanations, ranging from videotaping and closely analysing actual explanations (e.g. Geelan 2003) to conducting philosophical discussions of the topic divorced from empirical evidence (e.g. Norris et al. 2005). Treagust and Harrison (2000) analysed the lectures of Richard Feynman, who was widely regarded as an exemplary explainer.

Approaches have typically fallen into the two dimensions of 'what is' and 'what should be' – either seeking to understand the nature and features of explanations as they are 'in the wild' or seeking to describe, and to some extent prescribe, what constitutes a high-quality explanation.

There also exists research on explanations that is linked to other issues such as the use of educational technology (including distance and flexible modes of instruction) and to particular issues in the science disciplines such as multiple representation in chemistry. Issues of teacher content knowledge and explanation skills also need to be further elucidated.

An enormous amount of research remains to be done in this field – the surface has barely been scratched. Many of the key definitional and philosophical issues, if not exhausted, then at least have been sufficiently addressed to allow research to focus on finding good-quality empirical evidence to support much better understanding of the features and skills within the profession, and to find ways of teaching explanation to beginning science teachers that enhance science education.

Two frameworks that seem to me to have particularly rich potential for future research are the evaluative rubric developed by Sevian and Gonsalves (2008) and Thagard's (1992) work on analogies. The Sevian and Gonsalves framework is subtle and sophisticated enough to allow researchers to distinguish better between poor explanations resulting from poor content knowledge and those resulting from poor explanatory skills, so that attention in teacher education and professional development can be more precisely targeted for improving the quality of explanations. It also offers a scheme for explaining the important features of explanations to prospective science teachers in science education courses. Thagard's work offers similar potential in the narrower field of analogies, and allows the quality of analogies to be judged in some defensible way.

Combining these frameworks with continued close analysis of the explanations offered by classroom teachers, whether or not that close observation is aided by technological tools, such as video, offers huge potential for improving our knowledge of explanation.

Conclusion

Teacher explanation in science education has existed as a field of research interest at least since the 1970s, yet there remain too few studies scattered across too many issues to really serve science education at all levels. The research findings reviewed here are encouraging and compelling, and offer some guidance for teaching and teacher education, but there is much work still to be done.

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Chapter 66
Argumentation, Evidence Evaluation and Critical Thinking

María Pilar Jiménez-Aleixandre and Blanca Puig

In fact, men will fight for a superstition quite as quickly as for a living truth - often more so, since a superstition is so intangible you can not get at it to refute it, but truth is a point of view, and so is changeable.

Attributed to Hypatia of Alexandria, V century

Introduction

How is argumentation connected to the development of critical thinking? How does argumentation support the capacity of discriminating between claims justified in evidence and mere opinion, superstition or pseudoscience? These questions form part of a broader one: Which educational goals legitimise the introduction of argumentation in the classroom? Or, how can argumentation contribute to two types of objectives related, on the one hand, to learning science and, on the other, to citizenship?

Attention to the development of argumentative competencies in science education has been increasing in the last 15 years (e.g. Richard Duschl and Richard Grandy 2008; Sibel Erduran and María Pilar Jiménez-Aleixandre 2008). This interest is related to the role of argumentation, amongst others, in the appropriation of scientific practices, in the building of models and in the development of thinking skills. From a set of potential contributions of argumentation to education and science education goals that we have proposed elsewhere (María Pilar Jiménez-Aleixandre and Sibel Erduran 2008), this chapter focuses on supporting the development of critical thinking.

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Critical thinking is being used with a range of different meanings in the literature, from views defining it solely or mainly as a commitment to evidence, to others including, along the competencies related to evaluation of evidence, the challenge of arguments based on authority, or the capacity to criticise discourses that contribute to the reproduction of asymmetrical relations of power. The first section reviews a variety of meanings for critical thinking from the philosophy, psychology and science education literature. In the second section, we propose our own characterisation which constitutes the chapter's central argument: that evidence evaluation is an essential component of critical thinking, but that there are other components related to the capacities of reflecting on the world around us and of participating in it. The third section examines the contributions of argumentation in science education to the components of critical thinking, whereas the fourth discusses the evaluation of evidence and the different factors influencing or even hampering it. The chapter ends with some considerations about the development of critical thinking in the science classroom.

Different Meanings of Critical Thinking

There are several characterisations of critical thinking and the critical thinker used in different communities. We revise some influential notions about critical thinking from the field of philosophy, before turning to psychology. Some features of critical thinking, such as reflection and the use of criteria for judgement, are agreed upon by different philosophers, whilst there are debates on its components (e.g. dispositions), as well as on the possibility of testing these notions against empirical research.

Robert Ennis (1987, p. 10) defines critical thinking as 'reasonable reflective thinking that is focused on deciding what to believe or do'. This is a broad definition that, according to Ennis (1992), attempts to reflect the central tendency of usage of this term. He sees critical thinking as encompassing, on the one hand, a set of dispositions and, on the other hand, a set of abilities. These sets constitute a taxonomy, widely used in the literature, that can be considered as guidelines or goals for curriculum planning, as 'necessary conditions' for the exercise of critical thinking, or as a checklist for empirical research. By disposition, Ennis means an inclination or tendency to behave frequently in a certain way. Dispositions include for instance, seeking reasons, being open-minded or taking a position when the evidence is sufficient. Abilities, grouped in five basic areas, include analysing arguments, judging the credibility of a source or deciding on an action. As Anat Zohar, Yehudith Weinberger and Pinchas Tamir (1994) point out these skills partially overlap with scientific inquiry skills, such as testing hypotheses, planning experiments and drawing conclusions.

About the components, Harvey Siegel (1988) agrees with Ennis concerning the relevance of dispositions or tendencies, arguing that skills are not enough without the willingness, desire and disposition to base one's actions and beliefs on reasons. Christine McCarthy (1992) takes a different view, pointing out that the dispositions that Siegel and others associate with critical thinking are characteristics of the person, the thinker, and not features of the thinking. She claims that an account of critical thinking should specify the characteristics of the thinking itself, and considers that, whilst a certain disposition can be considered necessary conditions for being a critical thinker, this is not the case for critical thinking per se.

For Stephen Norris (1992), the different definitions of 'critical thinker' have consequences for educational practice, as one of the goals of theorising about critical thinking is to make school students better critical thinkers. As 'thinking disposition' is a central term in some of these theories, it is relevant to find out if this disposition exists. Norris suggests carrying empirical research to test it. Thus, these theories could provide hypotheses for empirical research to test, but Norris suggests that, in order to play this role, the theories of critical thinking must be framed so that their empirical implications are made clear. For instance, we need a clear account of what evidence would count for the presence or absence of a certain disposition. Norris concludes that, in order to serve the educational goal of fostering the development of critical thinking, theorists (philosophers) need to become more involved in empirical research.

From Ennis' set of dispositions and abilities, Siegel (1988, 1989) emphasises the disposition of critical thinkers to seek evidence for their beliefs. He views critical thinkers as those who are appropriately moved by reasons, having the disposition to properly assess the force of reasons. He conceives critical thinking as an educational ideal, requiring both the mastery of epistemic criteria that reasons must meet in order to warrant claims, and the tendency or attitude to value and seek good reasoning. For Siegel, the rationality of science is connected to its scientific method, which is characterised as a *commitment to evidence*. As a recommendation for a critical science education, Siegel (1989) suggests a focus on the study of reasons and evidence in science.

From the perspective of developmental psychology, the work of Deanna Kuhn offers a notion of critical thinking that agrees with the philosophical views summarised so far regarding the need for both competencies and dispositions, but criticises some of their features. Kuhn (2005) sets apart her work from previous writing by emphasising its basis on empirical evidence, taking a position aligned with Norris' suggestions discussed above. She criticises Ennis' taxonomy because, whilst giving a general idea of what critical thinking is, it leaves unanswered fundamental questions as 'the interrelationship among the various attributes that characterize critical thinking' (Kuhn 1991, p. 281). Kuhn also contends that these models do not provide a characterisation of the thinking processes. She defines critical thinking as reasoned argument, and her research has focused on identifying specific reasoning forms that are central to critical thinking and on showing how they are interrelated.

A summary of Kuhn's contributions towards these issues needs to mention, first, the relevance that she accords to the goals of equipping students for life's demands beyond the classroom. Second, she conceptualises thinking skills as a social activity or 'something people do, most often collaboratively' (Kuhn 2005, p. 13), embodied in the discourse that people engage in to advance their goals. From the different thinking skills, she emphasises inquiry and argument. These require a development of epistemological understanding, which Kuhn conceives as a progression through four steps or levels: realist, absolutist, multiplist (or relativist) and evaluativist. At the evaluativist level, knowledge consists of judgements: some opinions or claims are better supported by argument and evidence. This last stage is relevant for our topic, being the only one in which critical thinking is valued as a vehicle that promotes sound assertions (Kuhn 2005, p. 31). Kuhn's levels can be related to previous schemes, like that of William Perry's (1981), who argues that critical thinking is a matter of epistemological standards, which he views along nine stages or moves – also based in empirical studies – from uncritical acceptance of authority to independent, critical thinking.

Kuhn (1991) distinguishes different skills or abilities involved in critical thinking: to differentiate opinions or claims from evidence; to support claims with evidence; to generate opinions or theories alternative to their own and full counterarguments, including the evidence that would support them, and to generate rebuttals for the alternative theories by providing evidence supporting their own. As a summary of these influential perspectives from philosophy and psychology, we can say that there is a coincidence concerning the notion of critical thinking as reasoned argument, supported by the examination and assessment of evidence. Critical thinking is used with this meaning in other works from the field of psychology, such as the studies of Tony Anderson et al. (2001) about learning critical thinking skills.

This notion is also prevalent in most of the science education literature addressing critical thinking. For example, the Biology Critical Thinking project, reported in Zohar et al. (1994), quotes Ennis' definition and uses reasoning skills and critical thinking as interchangeable. The seven skills selected in their study are equivalent to reasoning and inquiry skills: recognising logical fallacies; distinguishing between findings and conclusions; identifying assumptions; avoiding tautologies; isolating variables; testing hypotheses; and identifying relevant information for answering a question.

A Comprehensive Notion of Critical Thinking: Commitment to Evidence and Emancipation

The notion discussed in the previous section takes into account only one component or set of components of critical thinking. Another set of components of critical thinking is related to emancipation, or the capacity to criticise discourses that contribute to the reproduction of asymmetrical relations of power (Norman Fairclough 1995). This second component draws from the perspectives of critical theorists and critical educators such as for instance reviewed in Karyn Cooper and Robert White (2007). On the one hand, critical theory is grounded in the work of Adorno and other philosophers from the Frankfurt School, and can be described as a reflection on the relationships amongst social goals, means and values. For critical theory, the goal of technical progress cannot be placed higher than democracy, and education is assigned a central role in social transformation. Jürgen Habermas (1981) conceives critical theory as a form of self-reflective knowledge that expands the scope of autonomy, thus reducing domination. Habermas' theory of communicative action gives people pre-eminence over structures, assigning them the potential to develop actions directed to social change. He distinguishes amongst technical, communicative and critical (or emancipatory) interests, which are directed to transform power relationships. It is this second meaning of *critical*, as commitment to emancipation or social justice, which we propose for combination with commitment to evidence.

A relevant notion for critical theory in education, cultural capital, comes from the work of the French sociologists Pierre Bourdieu and Jean-Claude Passeron (1970). Through empirical studies, Bourdieu and Passeron show how social inequalities are reproduced also through differences in cultural or symbolic capital: differences in access to what count as legitimate symbolic cultural tools amongst children of privileged and underprivileged background influence their academic opportunities and success.

On the other hand, critical education is more concerned with the transformation of daily work either in schools or in adult education. It draws from the traditions of innovative movements born in the turmoil of the years between the two World Wars, such as Célestin Freinet's (1969) 'People's school'. Freinet wrote his first books when he was arrested, for being a communist, in an internment camp by the Vichy government in 1940. Some of the innovations carried out by Freinet in his primary classroom involved the children in writing a weekly journal in three columns: we criticise, we praise, we demand. Freinet places students' writing and drawing at the core of his pedagogical proposals. A similar perspective, from the other side of the Atlantic, is to be found in Paulo Freire (1970), who worked with illiterate adults with the goal, not just to teach them to read and write, but also to empower them to understand the society around them and their own capacity to transform it. Freire proposes a problematising education, using resources such as analysing how different journals report a single event. For example, this strategy was used by Galician students to analyse the news about the Prestige oil spill (Jiménez-Aleixandre et al. 2004).

Our proposal for a more holistic characterisation of critical thinking, combining the evidence evaluation and the social emancipation components, is to consider it as the competence to develop independent opinions and to develop the ability of reflecting about the world around us and participating in it. Figure 66.1 summarises this characterisation and its components or dimensions.

A first component of this notion of critical thinking is to be able to evaluate knowledge on the basis of available evidence, which involves the use (and even the development) of epistemic criteria or standards to judge the knowledge claims subject to evaluation. The second component is related to dispositions, such as seeking reasons for one's own or others' claims and challenging the authority as sole support for claims, as opposed to uncritical acceptance of authority (e.g. experts, books, etc.). Whilst the first component deals with the evaluation of *claims*, the second relates to the evaluation of the reliability of the scientists or *experts* producing them, which is a critical scepticism that Norris (1995) suggests that students need to be taught. As Stein Kolstø and Mary Ratcliffe (2008) point out, scientists' judgements are made in social contexts and influenced by background assumptions; they do not always constitute hard evidence. We see these two components or sets of components as being part of argumentation.

A third component is the capacity of a person to develop independent opinions or, in other words, to elaborate her or his ideas, as opposed to relying on the views of others (e.g. family, peers, teachers, media). This does not mean a lack of attention to different views, but a careful evaluation of the information provided by different sources, of the assumptions behind them and of the extent of their support by evidence. We think that a crucial disposition in this component is to be prepared to challenge the mainstream ideas of one's own group or community. For example, it denotes a higher degree of independent thinking to be against capital punishment – an issue explored by Kuhn (2005) in her studies about argumentation – in some contexts and countries where it is legal, than to be against it in other countries where capital punishment has been abolished for many years. The difficulties that adolescents experience in opposing the opinions of their own group of peers are well known, which accounts for the relevance of social interactions and leadership in argumentation in small groups (David Eichinger et al. 1991; Jiménez-Aleixandre et al. 2000). Concerning scientific explanations, an example of this type of independent thinking, and the psychological and social difficulties involved in challenging the community views, is Copernicus or Giordano Bruno's proposal of heliocentric models in the sixteenth century against the prevailing geocentric view; for them, Bruno was burned at the stake in 1600. Charles Darwin's reluctance to make public his ideas about the origin of species, and particularly about the origin of man, and his fears of a confrontation with the socially-dominant creationism and with the religious beliefs of his wife, are well documented in his journals and notebooks (Adrian Desmond and James Moore 1992), and were one of the reasons for a delay of about 20 years in its publication. Howard Gruber (1981) shows how the images of scientists persecuted for their ideas surface in the notebooks since 1838: from the mention of the persecution of astronomers in notebook C, to the dream about hanging described in notebook M. As Gruber notes, Darwin had to be well aware of the critiques to Lamarck and Chambers: Chambers did not dare to sign with his name his 1844 book reviewing evidence of biological transformation. A hundred years before, Buffon had been forced to write a retraction of his theories about the age of the Earth. And Darwin attended a meeting of the Plinian society on March 27, 1827 when William Browne claimed that, as far as one individual sense and consciousness are concerned, mind is material and produced in the brain. After being recorded in minutes, these propositions were struck.

A fourth component is the capacity to analyse and criticise discourse that justifies inequalities and asymmetrical relations of power, which is connected to Habermas' meaning for critical as discussed at the beginning of this section. We see these third and fourth components as related to social emancipation and to citizenship.

Of course, these components are to be seen not as discrete, but as interconnected and sometimes overlapping. For example, all are based on evaluative judgements using available evidence, and independent thinking requires a disposition to challenge authority in certain instances. In the next section, through this revised notion, we discuss studies that are placed at the crossroads between argumentation and critical thinking.

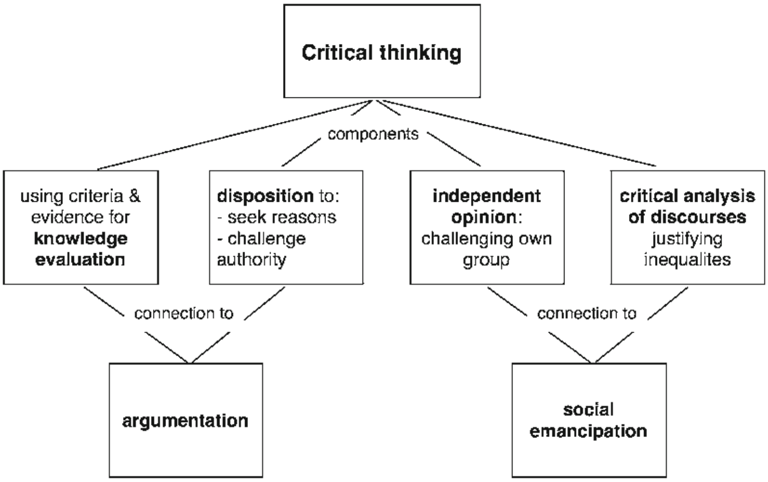

Fig. 66.1 A characterization of the components of critical thinking

Contributions to Critical Thinking from Argumentation in Scientific and Socio-Scientific Issues

Being a critical thinker and being able to develop independent opinions are necessary in order to be an active citizen in a democratic society. We propose that one of the contributions of argumentation to educational goals is to support the development of critical thinking. In this section, we examine the contributions of argumentation to the four components of critical thinking represented in Fig. 66.1 in two types of contexts: argumentation about scientific issues and argumentation and decision making about socio-scientific issues.

The contributions of argumentation to critical thinking can differ according to the nature of the context of the task and the issues being debated. Rather than a sharp distinction between purely disciplinary and socio-scientific arguments, we view them as placed in a spectrum with argumentation about scientific issues at one end and argumentation about socio-scientific issues at the other, as represented in Fig. 66.2.

This spectrum is related to the degree to which science issues are ‘value free’ or ‘value laden’ (Aikenhead 1985). The ‘value laden’ end corresponds to issues or activities set in a context where social, ethical, ideological and cultural values are relevant. As Kolstø and Ratcliffe (2008) indicate, in socio-scientific issues, science is involved in a social debate, typically concerning personal or political decision making related to health or environmental controversies.

Some examples of arguments about scientific issues that are located at the purely disciplinary end of the spectrum are: the debates about which snowman would first melt (the one with clothes on or the one without clothes); evidence supporting the notion that light rays originate in an illuminated object versus the notion that they

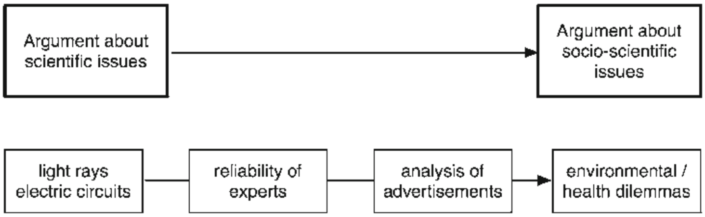

Fig. 66.2 Spectrum of argumentation in different contexts

originate in the eyes (Jonathan Osborne et al. 2004); predictions about electric circuits inside a black box (Gregory Kelly et al. 1998); or arguments about the causes of the yellow colour in farm chicken (Jiménez-Aleixandre et al. 2000). An example of arguments placed halfway through the spectrum could be the critical judgement of the reliability of scientific claims in articles (Kolstø et al. 2006), with students having to focus on scientific content and also on social aspects as institutional interests or competence of the experts. Closer to the socio-scientific end would be the critical analysis of scientific evidence supporting the claims in advertisements about cellulite reduction (Márquez et al. 2007). This critical analysis, besides combining knowledge about science concepts and about how to collect and analyze scientific evidence, is also influenced by cultural values related to a stereotyped ideal of beauty. Another example of this type of critical analyses may be arguments about the choice of material for window frames (Kolstø and Ratcliffe 2008), with justifications combining physical properties, environmental impact and egocentric values about cost and maintenance. Placed at the socio-scientific end of the spectrum, we would find arguments about genetic engineering dilemmas (Sadler and Zeidler 2005), the reliability of predictions about an oil spill (Jiménez-Aleixandre et al., 2004), the re-introduction of endangered species (Simonneaux and Simonneaux 2009) or James Watson's claims about genetic differences in intelligence between black and white people (Blanca Puig and Jiménez-Aleixandre 2008).

The contributions of argumentation to the first component of critical thinking, using criteria and evidence for knowledge evaluation, are clear because this component lies at the core of the argumentation competencies. One of the central features in argumentation is the development of epistemic criteria for knowledge evaluation (Jiménez-Aleixandre, 2008), which is a necessary skill to be a critical thinker. Students need to be able to develop criteria for choosing amongst conflicting views (Norris and Korpan 2000) and to develop skills in handling information for disentangling opinions and interpretations from facts (Russell Tytler et al. 2000). For these purposes, we think that there are no substantial differences to be expected between the contributions of the different types of argumentation contexts summarised in Fig. 66.2.

Regarding the second component of critical thinking, namely, dispositions, we can distinguish between dispositions of a more general character (seeking reasons, being open-minded and others proposed by Ennis) and disposition to challenge authority. The first type is relevant both for argumentative competencies and for critical thinking, and the practice of argumentation should contribute to them. Scientific arguments benefit from a critical analysis of the believability of experts and from overcoming uncritical acceptance of authority; for arguments closer to the socio-scientific side of the spectrum, we think that it is a requirement. It could be expected that this disposition to challenge authority would be particularly supported in socially relevant contexts. This is the case for the Jiménez-Aleixandre et al. (2004) study about students' arguments on the Prestige oil spill, for which high school students challenged the claims of the experts, appealing either to empirical evidence or to the affiliation of one of them with the tankers' owners. Also, in the Kolsto et al. (2006) study about the reliability of scientific claims, university students drew upon the underlying interests or critical attitudes of the sources.

We think that the contributions of argumentation to the third component, the development of independent opinions, could also be different in contexts placed in different positions in the spectrum although, in all the cases, there are difficulties in challenging one's own community, as discussed above. For scientific issues, students might be aware of the potential existence of one option that is better supported by available evidence – even in the cases when they favour alternative options – whilst socio-scientific issues possibly are associated with several options that balance positive and negative aspects. One instance is the choice of a heating system (Fins Eirexas and Jiménez-Aleixandre 2007), for which it is not possible to choose the 'good' option of a renewable energy source (commercially unavailable), being necessary to choose among the 'not-so-bad' ones. A consequence could be that, in socio-scientific contexts, students feel more free to seek an option that would not be assessed against the 'correct' one, so these contexts would better support the development of independent opinions. It has to be noted, however, that the construction of knowledge and the evaluation of knowledge claims about scientific issues are not the same in the scientific community, where proposing a new theory requires a high degree of independent thinking, as in the science classroom.

In the case of the fourth component, the capacity to criticise discourses justifying inequalities, we think that it is a specific contribution of argumentation in socio-scientific contexts, where dimensions as the economic interests of companies, the ethical issues involved in given research, or the environmental consequences on some regions of the planet of activities carried in another region, form the reasons considered when evaluating the different alternatives.

A summary of the contributions of argumentation to the four components of critical thinking could be that the development of the two first components is equally supported in scientific and socio-scientific contexts, but that the development of components three and four is more likely to be supported in socio-scientific contexts. However, these differences should not be interpreted as a call to design all or most argumentative activities around socio-scientific issues. This is not an implication that we would draw. The emphasis on one or the other end of the spectrum depends on the goals in each particular classroom, combining science learning and citizenship education.

Social Representations and the Evaluation of Evidence

On the other hand, bringing socio-scientific issues into the classroom could increase the complexity of the argumentation processes, creating difficulties for teachers in ways that we view as related to the potential problems discussed by Aikenhead (1985) about decision making in science-technology-society contexts. Next we focus on one of these difficulties: the different dimensions influencing evidence evaluation, which we see as the central feature of argumentation in scientific and socio-scientific contexts.

The evaluation of evidence is influenced by a variety of factors, including some related to the scientific content of the task, such as its degree of difficulty. The social dynamics of the group can be decisive in the choices, as discussed in the argumentation literature (Eichinger et al. 1991). An example is the effect of the roles that children adopt: Jane Maloney (2007) showed that in the groups from her study that debated more pieces of evidence, there was a pupil who took the role of information manager (summarising the evidence).

One difference between the evaluation of evidence in scientific and socio-scientific contexts is that it might be enough to weigh the scientific data and warrants in scientific contexts, but it is also necessary to take into account other dimensions of the problems in socio-scientific contexts. For example, decision making about environmental issues, such as waste management or building materials, might need to articulate economical costs, technical issues and environmental impact. Argumentation about genetic engineering could require balancing the potential benefits alongside the potential risks for ecosystems or human health, the social effects on farmers (particularly from developing countries, as the case of vanilla in Madagascar or gum Arabic in Sudan) who could lose their livelihood, ethical concerns about gene patenting and biopiracy, etc.

The articulation of ethical values with scientific evidence in socio-scientific contexts has been explored in an extensive research programme by Sadler, Zeidler and colleagues. Dana Zeidler and Troy Sadler (2008) propose that argumentation frameworks take ethical (or moral) concerns into consideration, suggesting that teachers highlight the connections between science and ethics, in a perspective of education for citizenship. Sadler and Zeidler (2005) examined students' reasoning about genetic engineering, interpreting it as distributed in three patterns: rational, based on reason and logic; emotive, driven by care and emotions; and intuitive, representing immediate feelings and reactions. They emphasise the descriptive (not evaluative) character of their framework: 'We reject the notion that arguments motivated by any one pattern are necessarily weaker or stronger than those represented by another pattern' (Zeidler and Sadler, p. 211), challenging the higher hierarchy accorded to scientific evidence in most argumentation frameworks.

We agree with Zeidler and Sadler about the need for integrating the ethical considerations in argumentation in socio-scientific contexts and for a descriptive framework to account for students' reasoning. However, we believe that there are some patterns that are stronger than others, and that teachers should focus their efforts in scaffolding the development of rational patterns of reasoning. Perhaps it is partly a question of the meaning accorded to different terms because, when describing rational arguments based on reason, we understand *reason* and *reasonableness* in Stephen Toulmin's (2001) sense of substantive argumentation historically (and, we would add, socially) situated and taking into account human interests in addition to the available evidence.

Although we think that it is desirable for students (and people) to integrate care and empathy in their reasoning, we would contemplate purely or mainly emotive reasoning as less stronger than rational reasoning. An example of the problems related to reasoning influenced by emotions is reported in by Martin Stanisstreet et al.'s (1993) study about pupils' attitudes to the uses of animals: whereas 75% of adolescents are against raising animals for food or clothing, less than 50% think that all animal species should be preserved. In our own work about resources management, we found that adolescents believe that using animal skin for furs is a more serious problem than the loss of cultivable soil. Probably this is related to dramatic campaigns against furs, contrasted with a geological entity with little emotional appeal. Another emotionally charged value influencing their arguments about soil management could be the notion of family property: students against regulating the building of second residences in cultivable land argue that people should be allowed to do whatever they choose in property belonging to their families for generations (Francisco Sóñora et al. 2001). Similar egocentric values were dominant in students' choices of PVC or hardwood for window frames (Kolstø and Ratcliffe 2008), without regard for environmental effects.

For analogous reasons, we argue that intuitive reasoning could be quite limited. What different people find outrageous (or conversely, sacred) can be something for which there is a wide ethical consensus, such as threats to human life or issues about which there is or has been no consensus. An example of these not-consensual issues may be positions rooted in intuitive prejudice and bias, as for instance the idea that women can study in universities (which historically has encountered fierce opposition from male students). In the present times, there are a number of countries where males find outrageous to their masculine identity the use of condoms in order to prevent AIDS transmission (an example of an intuitive pattern that should be modified in favour of arguments based on scientific evidence and on care and empathy for other people).

In other words, emotions and intuitions could bring positive dimensions to arguments, such as caring for people, or negative dimensions, such as egocentric or chauvinistic values. Critical thinking should help in disentangling the multiple dimensions involved in socio-scientific issues (e.g. 'stepping out' of one's own group or interest in order to reach a balanced viewpoint). The difficulties in overcoming egocentric values can be illustrated by Jiménez-Aleixandre and Marta Federico-Agraso's (2009) work about human cloning. When asked to provide two or more potential reasons for and against this type of research, 22% of the students with a biology background offered none against, with some of them explicitly stating that they could not think of any reason. By contrast all the students without a biology background stated at least one. Does it mean that the biology students were unaware of the ethical implications of such research? We prefer to interpret it as the influence of students' perceived professional identity as biologists (i.e. cloning research as a potential job opportunity that they were not ready to miss or challenge).

The question of professional identities leads us to examine how the evaluation of evidence can be affected by social representations, in the sense coined by Serge Moscovici (1961–1976) of socially, collectively constructed notions. In their discussion of the Laurence Simonneaux and Jean Simonneaux (2009) work on argumentation of the reintroduction of bears and wolves in France, Ramón López-Facal and Jiménez-Aleixandre (2009) point out how students' arguments ignored several pieces of the available evidence: that both Slovenian and Pyrenean bears belong to the same species; that there were no reliable sources about differences in behaviour (in other words, that Slovenian bears were not more aggressive); and that the bears' diet is predominantly (70%) herbivorous, not carnivorous. López-Facal and Jiménez-Aleixandre interpret that evidence evaluation was blocked by the identification with shepherds and the assumption of a shared socio-professional identity as agricultural practitioners. Influenced by associations with shepherds, students came to see Slovenian bears as fundamentally foreign. As Simonneaux and Simonneaux note, value systems tend to reproduce the dominant ideology that is then expressed as the individuals' own discourse.

Another example of the influence of social representations comes from our study of what high school students conceptualised as evidence for or against James Watson's claim about genetic differences in intelligence between black and white people (Puig and Jiménez-Aleixandre 2009). We found that a substantial proportion of students' responses (from 16% to 58% depending on the items) revealed implicitly determinist views, and some responses (25% for one item) reflecting explicitly determinist views. By this we mean stating and taking for granted that blacks are less intelligent than whites. In our opinion, this means that, despite scientific consensus about the interaction gene-environment, the social representations about human 'races', as scientific categories explaining behaviour and performances, are deeply rooted in students' minds.

Final Considerations

In this chapter, we propose a characterisation of critical thinking as the competence to develop both independent opinions and the ability to reflect about the world around us and participating in it. It is related to the evaluation of scientific evidence (a central feature of argumentation), to the analysis of the reliability of experts, to identifying prejudices (our own or others') and to distinguishing reports from advertising or propaganda. Thinking critically does not mean questioning all data, evidence and experts, but rather developing criteria for evaluating them. It could involve challenging one's own personal or collective interest and overcoming egocentric values.

It is suggested that argumentation in scientific and socio-scientific issues can contribute in different ways to the development of critical thinking by students. Because of its particular contributions, we support bringing socio-scientific issues into the classroom. It is necessary to be aware of the complexity of the argumentation and decision-making processes in both contexts: argumentation about real issues is closer to the more value-laden end of the spectrum and needs to consider other dimensions besides scientific content. But, from the students' perspective, scientific issues are also complex. The influence of social representations and other dimensions in the evaluation of evidence is examined, not with the purpose of discouraging the use of socio-scientific contexts, but as examples of the difficulties that can be expected when designing classroom activities and the need for careful scaffolding.

Our effort towards bringing together argumentative reasoning and critical theory is framed by Habermas' lasting contribution: according to Toulmin, 'to insist on the connection between knowledge and reasoning on the one hand, and human interests on the other' (Toulmin 2001, p. 165).

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Chapter 67
Constructivism and Realism: Dueling Paradigms

John R. Staver

If anyone can show that a particular scientist is right, it is that scientist … If anyone can show that you are mistaken, it is your opponents.

(Hull 1988, p. 348)

…'paradigms'. These I take to be universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners.

(Kuhn 1970, p. viii)

In general, skepticism takes the form of a request or justification of … knowledge claims, together with a statement of the reason motivating that request.

(Grayling 1996)

To be vibrant is to be "pulsating with life, vigor, or activity" (Mish 2003). Science education, like science, is a vibrant discipline. It pulsates due to competition among individuals and groups holding disparate views, as portrayed above (Hull 1988). One source of pulsation is the question: Can we justify that anything we know represents some aspect of reality? My purpose herein is to review an on-going dialectical discussion between communities of scholars that hold different views about whether or not knowledge represents reality, the nature of knowledge, and the process of coming to know. The adversaries, realism and constructivism, constitute different paradigms (Kuhn 1970) or models for characterizing knowledge and the

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process of coming to know, for conducting research, and for recommending best practices in teaching and learning science.

To achieve my purpose, I will take five steps: (1) define and describe knowledge; (2) describe realism, constructivism, and truth; (3) cite points of divergence, convergence, and peaceful coexistence; (4) review the key issue over which realism and constructivism collide from a constructivist perspective; and (5) offer a closing thought.

Knowledge

Merriam-Webster's Collegiate Dictionary (Mish 2003) defines knowledge as: "the circumstance or condition of apprehending truth or fact through reasoning" (p. 691). Scholarly study of the nature of knowledge and its justification is called epistemology and includes three components: features that define knowledge; conditions or sources of knowledge; and the limits of knowledge and its justification (Audi 1999). The history of epistemology extends back to the ancient Greeks and before, and the rich, diverse landscape of issues set forth and argued throughout its history prohibit any attempt herein to represent them; therefore, I return to the question stated above in order to introduce the protagonists in this paradigmatic debate.

Realism, Constructivism, and Truth

Realism

Three broad categories of answers to the question "Can we justify that anything we know represents some aspect of reality?" exist: "Yes"; "no"; and "withhold judgment." Idealists respond "no" agnostics reply "withhold judgment"; realists say "yes." Idealists and agnostics typically employ epistemological skepticism as portrayed in the introductory quotation (Grayling 1996) in making their choices. I do not imply here that practicing scientists who are realists do not employ skepticism in their work. They do, but the context of scientific skepticism focuses on whether or not the theoretical frameworks explain the natural phenomena studied, not whether or not the theoretical knowledge represents the natural world as it is.

Realism is the time honored philosophical position that a world exists a priori, external to, separate from, and independent of human consciousness, which also exists a priori. Realism is a theory of ontology, of reality's existence. Scientific realists argue that we come to know this world as it is, albeit imperfectly, through science. Assuming that reality exists and is comprehensible, science as a way of knowing begins with common sense and embraces realism through the generation of knowledge about empirical objects and events – natural phenomena – that are primarily independent of scientific theory. Because the methods of science are not without error and its knowledge claims are approximate, scientists feel warranted in approving the strongest findings of science as knowledge that represents these objects and events in reality (e.g. Gauch 2003).

Truth

Realism, the view that reality exists, and truth as a representation of reality are not identical. When we say that knowledge represents reality, we say that:

> … these representations, such as beliefs and statements, purport to be about and to represent how things are in reality. To the extent that they succeed or fail, they are said to be true or false, respectively. They are true if and only if they correspond to the facts in reality. This is (a version of) the correspondence theory of truth. (Searle 1995, p. 151)

Truth as correspondence is not implied by realism because no name is specified for the relation between knowledge and reality. Other truth theories can be used within a realist perspective. Truth as correspondence, however, does imply realism because any true knowledge claim must correspond with its object, which is reality (Searle 1995).

Truth as correspondence is the venerable theory of truth in epistemology. There exists, however, another, more recent theory of truth, called truth as coherence. Knowledge is coherently true when its various assembled components hold together in relation to each other, thereby forming a consistent or coherent network.

Constructivism

Constructivism is a diverse school of epistemological thought, with two dominant strands, radical/psychological and social constructivism. Today's radical and social constructivist views are descended from somewhat different sources. Regarding radical constructivism, the Italian philosopher Giambattista Vico (1668–1744), who labored to distinguish mysticism from rationality, was the first scholar to set forth the notion that humans actively construct rational knowledge (Glasersfeld 1995). That humans actively construct knowledge is a foundational element of all constructivist theory. Immanuel Kant's (1724–1804) idealism (e.g., Kant 1995) contains this element, the concept of space and time as structures in the human mind, and other notions, thereby making important constructivist contributions a century later. The trail of Kant's ideas to radical constructivism in modern science education leads to Jean Piaget (1896–1980) and Ernst von Glasersfeld. Piaget's genetic epistemology (e.g., Piaget 1970) describes the individual's active internal formulation and pragmatic characterization of knowledge as a higher function of the biological processes of assimilation and accommodation. Glasersfeld (e.g., 1995) articulates radical constructivism as an epistemology, the root paradox as the point of collision between constructivism and realism, and a history of constructivist concepts and scholars.

Radical constructivism, in contrast with realism, does not assume the existence of external reality a priori. Advocates of radical constructivism are sometimes labeled as solipsists, but radical/psychological constructivism should be viewed as an escape from solipsism. Readers who seek to know the details of such an escape should consult Foerster (1984) or Staver (1998).

Radical constructivism contains four core assertions. First, an individual does not receive knowledge from external sources through the senses or via communication with others; rather, a person actively and internally builds up knowledge. Second, whereas others do not pass their knowledge to an individual, social interaction with others is a core element in an individual's active, internal construction of knowledge. Third, individual cognition is functional and adaptive in a biological context; functional refers to the notions of fit and viability, and adaptive refers to evolution. Fourth, the purpose of cognition is not to understand reality as it is; rather, the purpose is to organize an individual's experiences, thereby increasing the coherent understanding of an individual's experiential world. Radical/psychological constructivism embraces a coherence theory of truth (Glasersfeld 1995).

Social constructivism in today's science education is a blend of three sub-types. One stream flows from Kant and Kuhn, describing scientific work as influenced by a quasi-metaphysical causal structure based in the dominant paradigm; a second is tied to the concept of science as a social process that is vulnerable to factors that influence all social processes; the third is the strong program in the sociology of scientific knowledge, in which social power relations in the broad community and the scientific community largely or exclusively determine scientific knowledge (Boyd 2002). Social constructivism contains three core assertions. First, humans are able to develop meaning in language because their social interdependence serves as the channel for such development. Second, language occurs within a context of social interdependence; therefore, its meaning is dependent on this context. Third, the function of language is primarily communal, in that it serves as the conduit for establishing and maintaining relationships among the individuals within and across communities (e.g., Gergen 1995). Social constructivism, like radical constructivism, embraces a coherence theory of truth.

Points of Convergence and Divergence Between Radical and Social Constructivism

The principal point of divergence between radical/psychological and social constructivism lies in their respective foci. Social constructivism is an epistemological model for using language to study the making of meaning in groups. Radical constructivism, on the other hand, is an epistemological model for examining cognition in an individual as he or she makes meaning of experiences. Psychological and social constructivism also share much in common beyond their conception of truth as coherence. Their principles, introduced above, can be integrated as follows:

> First, knowledge is actively built up from within by each member of a community and by a community itself … Second, social interactions between and among individuals in a variety of community, societal, and cultural settings are central to the building of knowledge by individuals as well as the building of knowledge by communities, societies, and cultures. Third, the character of cognition and a language, which is employed to express cognition is functional and adaptive. Fourth, the purpose of cognition and language is to bring coherence to an individual's world of experience and a community's knowledge base, respectively. (Staver 1998, pp. 504–505)

Lev Vygotsky (1896–1934), the Russian psychologist who coined the term "zone of proximal development," did seminal work on the social character of human cognition. Vygotsky's work was largely unavailable in the West during his working years, yet he is perhaps the exemplar of a scholar who worked at the intersection of psychological and social constructivism (Kozulin 1990).

Constructivism and Realism: Points of Peaceful Coexistence

Before describing the competition between constructivist and realist views in science education, I think it is well worth noting areas in which little or no competition exists.

In their report on how learners learn, Bransford et al. (2000) characterize paradigmatic changes in research on the human mind: "a new theory of learning is coming into focus that leads to very different approaches to the design of curriculum, teaching, and assessment than those often found in schools today" (p. 3). Also referring to the new model as a "new science of learning" (p. 9), Bransford et al. present research-based summaries on how students learn, and set forth implications for teaching and classroom learning environments. Among the points made about learning are: "… its emphasis on learning with understanding" (p. 8) and "…its focus on the processes of knowing" (e.g., Piaget 1978; Vygotsky 1978). Moreover, "In the most general sense, the contemporary view of learning is that people construct new knowledge and understandings based on what they already know and believe" (p. 10). This quotation contains five citations of Piaget's work and two citations of Vygotsky's work. With respect to teaching, Bransford et al. assert: "the teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas" (p. 21). Regarding learning environments, "Schools and classrooms must be learner centered" (p. 23). Whereas their personal epistemological views are unknown to me, Bransford et al.'s discussions of how students learn, implications for teaching, and learning environments are consistent with implications of constructivist epistemology. I take this as an indication that constructivist epistemology, while perhaps not representing the dominant epistemological view in the development of a new science of learning, has nonetheless served as an influential contributor. Moreover, employing "constructivism as a referent for teaching and learning" (Tobin and Tippins 1993, p. 3) has gained acceptance, even respect, among researchers and scholars in science education as well as among P-12 teachers of science. Additional early indications of such acceptance were provided by constructivism's critics (e.g., Matthews, 1992; Osborne, 1996; Phillips, 1995) who:

> … acknowledge its contributions such as: (a) moving epistemological issues into the foreground in discussions of learning and curriculum; (b) providing empirical data to enhance our knowledge of difficulties in learning science; (c) fostering the development of innovative methods of science teaching; and (d) increasing our awareness of learners. (Staver 1998, p. 501)

In the last 15 years or so, terms such as "constructivist learning environment," "constructivist teaching," "constructivist learning," and "constructivist curriculum" (occasionally the term "student-centered" is substituted) have become acceptable in the practice literature, but less so in the research and scholarly literature of science education. Regarding the reason, my working hypothesis is that practitioners and administrators in the K-12 sector do not yet understand that constructivism and realism are epistemological models with implications for teaching, learning and learning environments, not learning, instructional, or learning environment models.

Constructivism and Realism: The Point of Collision

Despite the agreements discussed above, constructivists and realists remain deeply divided over the question: Can we justify that anything we know represents some aspect of reality? My brief synopsis of the current state of the conflict is based on Boyd (2002) and Ladyman (2007). Readers will notice that I present the issue in the context of science, not science education. Science itself has historically embraced realism, and science education has followed the lead of science, which represents the more difficult domain.

Scientific realists take the position that unobservable entities predicted and described by science's strongest theoretical frameworks exist. The strongest argument in support of scientific realism is known as the no-miracles argument, which holds that science's success rests on the condition that scientific theories are at least approximately true explanations and predictions of reality. If this condition were false, then science's success as a way of knowing would be miraculous.

A new form of realism, called structural realism (Worrall 1989), attempts to represent the strengths of each adversary while simultaneously avoiding each competitor's weaknesses. Structural realism does not accept scientific realism, with its acceptance that the strongest theories explain and predict the nature of unobservable entities that are the source of observable natural phenomena. Simultaneously, structural realism does not take antirealist views about science. Instead, structural realism advocates an epistemic commitment only to the mathematical and structural concepts of scientific theory. Such a commitment recognizes structural retention throughout changes in theory, dodges the continuing theory change argument, and denies the characterization of science as a miraculous enterprise.

On the other hand, skeptics stand behind the under-determination argument and an argument based on continuing radical change in theoretical frameworks over the course of the history of science. The under-determination argument holds that any competing theory can be demonstrated to be equally empirically adequate to its competitors with respect to observable phenomena, but evidence concerning any competing theory's explanations and predictions of unobservable phenomena is impossible. Consequently, making a decision between empirically equivalent, competing scientific knowledge of theoretical entities is under-determined, even in the presence of all possible observable data. The under-determination argument is effective only when it is applied to large-scale scientific conceptions of reality.

The second skeptical argument contemplates the history of science, portraying it as a theoretical graveyard, with past theories that insufficiently explained and predicted natural phenomena, and were subsequently replaced by new theories. Given this lengthy, rich history of theoretical abandonment, we should expect that current scientific theories will be left behind; thus, we should not think they reflect reality.

Scholars from other fields as well philosophers throughout history have voiced skepticism in a variety of contexts, all of them controversial. Let us consider three examples. First, linguists view language and thought as closely related; however, much controversy exists with respect to the nature of the relationship. The Sapir-Whorf hypothesis sets forth two relations: Linguistic relativity – language shapes culture – and linguistic determinism – language influences thought. The strength of each aspect of the relation and their relative strength with respect to each other remain hotly debated issues nearly eighty years after Sapir and Whorf first asserted that:

> Human beings do not live in the objective world alone, nor alone in the world of social activity as ordinarily understood, but are very much at the mercy of the particular language which has become the medium of expression for their society. It is quite an illusion to imagine that one adjusts to reality essentially without the use of language and that language is merely an incidental means of solving specific problems of communication and reflection. The fact of the matter is that the 'real world' is to a large extent unconsciously built upon the language habits of the group. No two languages are ever sufficiently similar to be considered as representing the same social reality. The worlds in which different societies live are distinct worlds, not merely the same world with different labels attached … We see and hear and otherwise experience very largely as we do because the language habits of our community predispose certain choices of interpretation. (Sapir 1958 [1929] p. 69)

Second, space and time are two fundamental concepts that humans use to interpret experience; however, where do space and time reside?

> Space and time are sensible objects in appearance, not representations of an object *in itself.* It is the coordination of the manifold of intuition under one concept of empirical representation, insofar as both are made by the subject, rather than given to it, and the latter presents itself and constitutes an absolute whole. (Kant 1995, p. 176)

Third, the problem of the criterion; this paradox ranks among the most important and difficult problems in philosophy:

> To know whether things really are as they seem to be, we must have a *procedure* for distinguishing appearances that are true from appearances that are false. But to know whether our procedure is a good procedure, we have to know whether it really *succeeds* in distinguishing appearances that are true from appearances that are false. And we cannot know whether it does really succeed unless we already know which appearances are *true* and which ones are *false*. And so we are caught in a circle. (Chisholm 2002, p. 590).

In an earlier publication, I presented a case for constructivist epistemology as sound theory for explaining the practice of science and science teaching. My argument was based primarily on epistemological concepts – truth, rejection of solipsism, experience, instrumentalism, and relativity (Staver 1998). I will say nothing further herein about the rejection of solipsism, and instrumentalism. I am deeply skeptical that further epistemological discussions will resolve any or all of the above-mentioned problems, yet I am cautiously hopeful that science itself holds promise to further our understanding of these problems. My earlier discussion on experience and relativity included a scientific as well as an epistemological perspective; therefore, I will focus herein on additional scientific information about experience, specifically about consciousness as the source of experience and vision as a specific aspect. This information is based on an article published in *Cultural Studies in Science Education* (Staver 2010). I begin with consciousness.

Consciousness

Consciousness is composed of two categories of awareness, primary and higher order: "Primary consciousness is the state of being mentally aware of things in the world, of having mental images of the present… higher order consciousness involves the ability to be conscious of being conscious" (Edelman 2004, p. 9). Scientific work on human consciousness and on *homo sapiens* as a species descended from simpler forms of life is conducted under the auspices of evolutionary theory. The human brain's ability to portray nature in divergent and viable ways is the product of heritable variation and natural selection (Changeaux 2004). Human consciousness and cognitive function are emergent capacities of the electrical and biochemical activity and biological architecture of the human brain (Edelman 2004).

Applying evolutionary theory to consciousness as a phenotypic property of a living entity raises a fundamental question: Do consciousness and the capacity for cognitive function and knowledge as emergent properties of the brain's activity confer on humans the capacity to know nature as it is or to survive and thrive better in nature through our capacity to organize our experiences better than our evolutionary relatives who also exhibit consciousness? Humans' nearest living evolutionary relatives are the great apes, and more than 90% of our genomes are identical. Among the great apes, our closest living evolutionary relative is the chimpanzee; these two sets of genomes are about 96% identical. Exhibiting consciousness, does a chimpanzee construct knowledge that corresponds to nature as it is, or does a chimpanzee construct knowledge that helps it succeed by organizing its experiences? If the answers to these questions are no and yes, respectively, then how should we respond with respect to humans?

Vision

Normal humans use five senses; we see, hear, smell, touch, and taste to interact with a world external to, separate from, and independent of our consciousness. Because vision dominates the other senses and because vision, more than the others, appears to permit humans to see nature as it is, a brief look at research on vision is appropriate.

Regarding the question posed above, two vision scientists write: “What, then, is wrong with the seemingly sensible idea that the purpose of vision is to perceive the world as it is and that this obviously beneficial goal is achieved by neuronal hardware that detects the elemental features of the retinal image and, from these, reconstructs a representation of the external world according to a set of more or less logical rules instantiated in visual processing circuitry” (Purves and Lotto 2003, p. 5)? Their answer is that “the sources of any retinal stimulus (and thus its significance for subsequent action) are unknowable directly” (p. 5), and “the retinal image also conflates the arrangement of the underlying objects in space” (p. 5). Last, they offer a caution: “Rather, the discrepancies between retinal images and the related percepts (‘illusions’) are the signature of an empirical strategy of vision in which percepts are neither correct nor incorrect representations of reality but simply a consequence of having incorporated into visual processing the statistics of visual success or failure in phylogenetic and ontogenetic experience” (p. 15). These assertions converge on Foerster’s (1984) principle of undifferentiated encoding, that a surface nerve cell’s response is to encode only how much stimulus it receives, not the physical nature of the source of the stimulus.

Quantum Mechanics

At a fundamental level, individual surface receptor neurons, when sufficiently stimulated, send electrical signals along nerve pathways to the brain, where more electromagnetic, biochemical activity occurs in complex neural networks. Quantum mechanics explains such electromagnetic activity at a foundational level. Quantum mechanics predicts as well or better than any theoretical framework in the history of science. No prediction of quantum mechanics has been demonstrated by experiment to be incorrect, and the theoretical bedrock of about one-third of our economy is quantum mechanics. Modern technology that uses transistors, lasers, and nuclear magnetic resonance is built on a quantum mechanical platform (e.g., Rosenblum and Kuttner 2006).

Despite its superlative predictive record and extensive practical applications, quantum mechanics remains a controversial theory because it ultimately connects the well-defined discipline of physics with the ill-defined concept of consciousness. (A full treatment of this controversy is well beyond the scope of this essay. Readers seeking largely non-mathematical discussions may consult Hey and Walters (2003), Rae (2004), or Rosenblum and Kuttner (2006)). Specifically, the results of quantum experiments present an enigma about the nature of reality that challenges our common sense foundation of scientific inquiry and humans’ classical view of the world in terms of realism. In brief, the enigma is “…observation creates the reality observed” (Rosenblum and Kuttner 2006, p. 99). Regarding common sense “is it not just common sense that one object cannot be in two distant places at once? And, surely, what happens here is not affected by what happens at the same time someplace very far away. And does it not go without saying that there is a real world “out there," whether or not we look at it? Quantum mechanics challenges each of these intuitions by having (conscious) observation actually *create* the physical reality observed" (Rosenblum and Kuttner 2006, pp. 3–4). Moreover, these challenges are well documented by experimental results, which show that one object can be in two distant places at once, events here can be affected by simultaneous events at great distances, and conscious observation creates reality.

Quantum mechanics was founded, defined, and described by Planck, Einstein, Born, Heisenberg, Bohr, de Broglie, Schrödinger and others during the first part of the twentieth century. Einstein, Schrödinger, and others verbalized their discomfort with the implications of quantum theory. Bohr, Heisenberg, and their colleagues developed the Copenhagen interpretation, which competed with other interpretations and won the support of most physicists in the early twentieth century because it allowed them to ignore the concept of a conscious observer influencing the nature of reality beyond the level of microscopic entities. Others, as did Schrödinger, asserted that we should listen because nature is sending us a message: "The urge to find a way out of this impasse ought not to be dampened by the fear of incurring the wise rationalists' mockery" (Erwin Shrödinger, quoted in Rosenblum and Kuttner 2006, p. 202).

A Final Thought

Knowledge constructed through research is considered stronger when it is supported via multiple, independent lines of evidence. As researchers, we routinely demand that research include multiple, independent lines of evidence, and our skepticism diminishes only when empirical results from independent lines of evidence support theoretical explanations and predictions. Nearly a century and a half after Darwin first published his research, evolution remains the single unifying theoretical framework across the broad expanse of the life sciences because scientific evidence in several areas within the life sciences as well as from astrophysics, geology, physics, chemistry, and anthropology continues to provide support for evolution's explanations and predictions (National Academy of Sciences and Institute of Medicine 2008).

Competition between realism and constructivism hinges on three points: the purpose of experience; the subjectivity of experience; and the absence of lines of evidence independent of experience. Evolution tells us that we make meaning of experience to survive and thrive in our experiential world. Quantum mechanics reminds us that we have the capacity as conscious beings to create the reality that we observe. The root paradox and the problem of the criterion point out to us the absence of evidence that is independent of experience. Humans possess one and only one connection – experience – with a world external to, separate from, and independent of our consciousness. Whereas multiple lines of evidence within experience are the empirical foundation of strong scientific theories, constructivists continue to withhold judgment as to whether knowledge represents reality until knowledge completely independent of human experience can be cited in support of a knowledge claim. Given these three points, it seems rather ironic that such an argument occurs.

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Chapter 68
Capturing the Dynamics of Science in Science Education

Michiel van Eijck

The broad aim of science education is scientific literacy (i.e. the forms of knowing the students will require as citizens in a scientifically and technologically sophisticated society of tomorrow). In contemporary knowledge societies, the production of scientific knowledge is unprecedented in scale and becoming increasingly reflexive, transdisciplinary and heterogeneous. This inherently increasing dynamics of science faces us with the problem that the level of scientific literacy with which students are being equipped within schools is getting out of pace with the level of scientific knowledge that is produced and applied in other parts of society.

At the heart of the problem is the question of what we mean by scientific literacy. Indeed, what scientific literacy is taken to be depends very much on the conceptions of science discursively associated with it. If scientific literacy is defined in terms that fail to grasp the dynamics of science, then students cannot be properly equipped with the knowledge that they will require as citizens in such societies. This raises the question of whether and how definitions of scientific literacy appropriate the dynamics of science. This chapter briefly reviews the science education research literature related to these questions.

This chapter takes three turns. First, a contemporary framework from the social studies of science is laid out in order to grasp the dynamics of science in contemporary knowledge societies. Next, drawing on this theoretical frame, the science education research literature is reviewed, with the aim of understanding how definitions of scientific literacy address the dynamics of science. This review illustrates that the dynamics of science are appropriated by a definition of scientific literacy as an emergent feature of collective human activity. Finally, the implications of this claim for science education are discussed. It is argued that scientific literacy understood as a collective entity requires a science education in which the learners' agency is central.

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Capturing the Dynamics of Science

The dynamics of science is a rather young research topic. Sparked by a sociological turn in the philosophy of science introduced by Thomas Kuhn (1970), researchers became interested in what scientists actually *do* and how their actions shape scientific knowledge. Since the late 1970s, an increasing number of studies were setup with the aim of monitoring how scientists go about their everyday work in laboratories, at conferences and in the field. Bruno Latour and Steve Woolgar (1986) were among the first social scientists to produce ethnographies of the manifold and complex ways in which natural scientists produce scientific knowledge. Ethnographies like these undermined the possibility of any logical reconstruction of the processes that legitimise scientific theories that philosophers of science, such as the logical positivists and Karl Popper (1959), were after. Put shortly, it appeared that the 'scientific method' is a myth. Simultaneously, scholars in this discipline developed sociocultural frameworks that allowed a better understanding of the dynamics of science than a logical reconstruction based on ready-made science.

One common framework for understanding the dynamics of science is actor-network theory, which resulted from the work of Bruno Latour (1987) and Michel Callon (1991) in their attempts to reveal the dynamics of the infrastructure that constitutes the often-static accounts of scientific and technological achievements. They recognised that science-in-the-making develops dynamically in time and space and cannot be described by temporally and spatially static elements that are discursively associated with the ready-made science that one might find, for example, in science textbooks. These static elements commonly reduce accounts of scientific and technological artefacts to categories that are natural (the things 'out there in the natural reality' discovered by scientists), social (the 'heroic' scientists) or discursive (formulae such as $E = mc^2$ and other texts that can be commonly found in science textbooks). Hence, to describe how science-in-the-making occurs, they developed a non-reductionistic approach by taking into account simultaneously all categories (social, natural, discursive) that were hitherto considered independently. Pivotal in this approach is the idea of actor-networks, which merge the two terms of actor and network which usually are featured as opposites in the social sciences. However, according to Callon:

> …it is not just another attempt to show the artificial or dialectical nature of these classical oppositions. On the contrary, its purpose is to show how they are constructed and to provide tools for analyzing that process. One of the core assumptions of ANT is that what the social sciences usually call 'society' is an ongoing achievement. ANT is an attempt to provide analytical tools for explaining the very process by which society is constantly reconfigured. What distinguishes it from other constructivist approaches is its explanation of society in the making, in which science and technology play a key part. (Callon 2001, p. 62)

Hence, focusing on the constant reconfiguration of society – the society-in-the-making – allows us to understand the dynamics of science and technology as playing a key role. A characteristic for this holistic approach is the absence of a presumed boundary between nature and culture. Thus, there is the premise of symmetry between human actors and nonhuman participants (artefacts, 'natural' entities) in

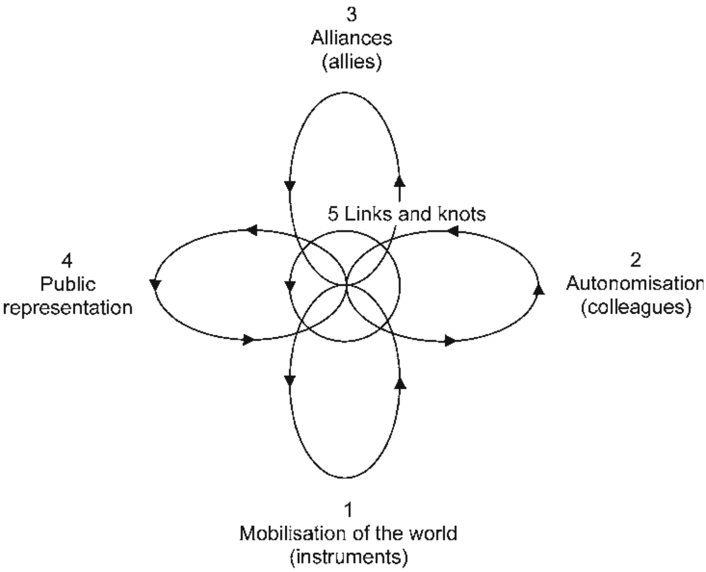

Fig. 68.1 Actor-network theory-based model of the dynamics of science (after Latour 1999)

the way in which they act and are acted upon in actor-networks. For instance, both Einstein and $E = mc^2$ can be considered actants in the developing actor-networks that constitute reconfigurations of society.

One implication of actor-network theory is that the dynamics of science cannot be appropriated by focusing only on the scientific concepts and the 'context' in which they are used, because this would again result in a reduction of scientific and technological artefacts to either natural, social or discursive categories. Models of the dynamics of science based on actor-network theory overcome this reduction by showing how such conceptual and contextual elements result from the flow of human actors and nonhuman participants through actor-networks developing over time. For capturing the dynamics of science, at least five loops have to be taken into account simultaneously (Fig. 68.1).

Mobilisation of the world, the first loop in Fig. 68.1, refers to 'all the means by which nonhumans are progressively loaded into the discourse' (Latour 1999, p. 99). It is the logistics of science, dealing with surveys, instruments and equipment, by which the world is converted into inferences, starting at sites and aiming at transportation towards laboratories where the world is assembled and contained into increasingly encompassing collections and representations. The second loop represents how a researcher finds colleagues and is called autonomisation, which 'concerns the way in which a discipline, a profession, a clique, or an "invisible college" becomes independent and forms its own criteria of evaluation and relevance' (pp. 101–102). This loop thus includes the institutionalising of scientific enterprises and the inherent formation of what Karin Knorr Cetina (1999) calls 'epistemic cultures'.

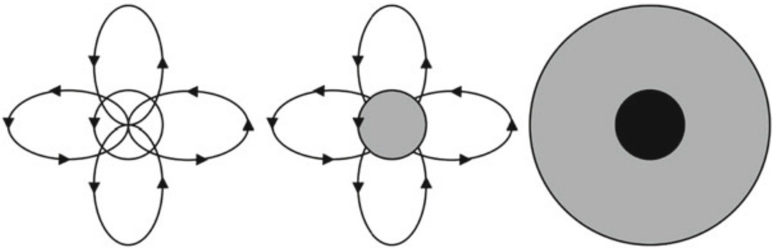

Fig. 68.2 Decreasing appropriation of the dynamics of science (after Latour 1999)

The third loop in Fig. 68.1 – alliances – shows that no scientific enterprise is completely autonomous, but is dependent on allies. It concerns institutions, such as the military, industry and government, which are interested in physics, chemistry and political science, respectively. The fourth loop is public representation, which is the process by which novel objects of science become massively socialised and part of the discourse in the public domain. For instance, whereas the word 'atom' was once a particular name used mainly in physic laboratories, it is today part of daily speech. Finally, the circle in the centre, the fifth loop in Fig. 68.1, refers to the conceptual elements, but this is envisioned as a series of links and knots that keep the other loops tightly together rather than the 'conceptual content'. This is not to say that it is less 'hard' than scientific concepts, but 'this hardness is not that of a pit inside soft flesh of a peach. It is that of a very tight knot at the center of a net. It is hard because it has to hold so many heterogeneous resources together' (p. 106). Collectively, the five loops in Fig. 68.1 are what Latour (1999) calls metaphorically the science's blood flow for which the fifth loop functions as the heart – it keeps the other loops running. If there were no fifth loop, the other four would die off at once. As such, the concepts of science have a different topology: 'The content of science is not something contained; it is itself a container' (p. 108).

Actor-network theory allows us to understand how a strong focus on the conceptual content of science easily leads to a static, canonical model of science that misappropriates its dynamics (Fig. 68.2). If the links and knots (left) are excised from the other four loops in Fig. 68.2, it will be transformed in a core (middle). The other four now-disconnected loops form a sort of 'context' of no relevance for defining the inner core. The result is a static conceptual content encompassed by an opaque 'context' in which the loops cannot be distinguished anymore (right) in Fig. 68.2.

This brief introduction in actor-network theory shows that conceptions of scientific literacy that appropriate the dynamics of science are those that provide the tools to exemplify conceptual elements as links and knots, that is, as containers and not as something contained. In addition, such conceptions should account for ways in which the links and knots hold together dynamic loops such as mobilisation of the world, autonomisation, alliances and public representation.

Definitions of Scientific Literacy and the Dynamics of Science

Since its emergence in the 1950s, the concept of scientific literacy has always been hard to define. However, within the many different definitions in the research literature, three trends can be distinguished that are each still present today. In what follows, each of these trends is reviewed to clarify how definitions of scientific literacy appropriate the dynamics of science.

Scientific Literacy as the Aim of Science Education

The concept of scientific literacy has always been associated with the aims of science education. Paul DeHart Hurd (1958) was among the first who introduced the concept in the North American academic debate on curriculum reform. At the time, there was much confusion about the purpose of science education. World War II had brought concerns about catastrophic uses of science, such as the atomic bomb. In addition, the launch of the Sputnik which showed the Russians' scientific leap forward raised awareness of the role of science in safeguarding national security. As a result, the aim of science education was more than only contributing to an increased output of highly specialised scientists and engineers. In addition, every educated person had to be literate in science because society required citizens who could appreciate and understand what scientists and engineers were doing.

Despite concerns about the accountability of science to the society, scientific literacy was usually articulated as the attribution of scientific 'content' to the student. In addition, knowledge was commonly defined in terms of cognitive objectives, which limited the theorising of such scientific 'content'. The work of Lawrence Gabel (1976) is representative of early research on scientific literacy. In order to bring coherence to the many different definitions of scientific literacy, the literature was reviewed in terms of Benjamin Bloom's *Taxonomy of Educational Objectives* (1956). This kind of work was influential. For three decades after the birth of the concept, definitions of scientific literacy were almost exclusively in terms of attributing particular science content to the individual. Even today, major curriculum reform documents such as *Benchmarks for Science Literacy* (AAAS 1993) and the *National Science Education Standards* (NRC 1996), as well as their seminal predecessor, *Science for All Americans* (Jim Rutherford and Andrew Ahlgren 1989), treat scientific literacy by and large in terms of the scientific content that students are supposed to learn and know.

Regarding the appropriation of the dynamics of science, it is important to distinguish between scientific literacy, as a concept referring to the aims of science education in terms of scientific content, and scientific literacy in terms of knowing and learning. For instance, in a recent review of George DeBoer (2000, p. 592, emphasis added) scientific literacy is defined in terms of nine distinct aims of science teaching, of which one reads as follows: 'Science classes should give students the *knowledge* and *skills* that are useful in the world of work and that will enhance their long term employment prospects in a world where science and technology play such a large role'. Aims like these can be found repeatedly in major curriculum reform documents. However, aims like the above do not make clear exactly what will change when a science class gives students 'knowledge' and 'skills'. In other words, such definitions do not articulate the nature of the cognitive entity that is, for instance, useful in the world of work and that will enhance students' employment prospects in a scientifically and technologically sophisticated world. Accordingly, such definitions blur how scientific literacy appropriates the dynamics of science, despite the explicit referents to the latter. That is, although the previously-mentioned definition of scientific literacy refers to the alliance between science and the world of work, it does not make clear how this aim exactly contributes to understanding this aspect of the dynamics of science. Indeed, having the knowledge and skills that are useful in the world of work does not guarantee any knowledge of how the practice of professionals plays into the dynamics of science. Evidentially, this definition of scientific literacy includes a focus on science content that overshadows its nature as the knots and links pertaining to the dynamics of science (see Fig. 68.2). Hence scientific literacy defined in terms of content-based aims of science education does not appropriate the dynamics of science. For such an appropriation, scientific literacy should be defined in terms of what it means to know and to learn.

Scientific Literacy as Individually Constructed Knowledge

During the 1980s, science educators started to explicate in more detail what the concept of scientific literacy meant in terms of knowing and learning. This had to do with the emergence of constructivism as a dominant framework in science education research. As a result, researchers attempted to illustrate how knowledge is *constructed* in the process leading to increased scientific literacy. For instance, *Science for All Americans* explicitly refers to this process: 'People have to construct their own meaning regardless of how clearly teachers or books tell them things. Mostly, a person does this by connecting new information and concepts to what he or she already believes' (Rutherford and Ahlgren 1989, p. 198). Nevertheless, definitions of scientific literacy in terms of the aims of science education that emphasise scientific content were still dominant. Therefore, Piagetian versions of constructivism (1957) were applied to define scientific literacy in terms of what it meant to know. The resulting curriculum reform documents focused on knowledge as individual cognitive entities, which 'at least as exemplified in science education research, tend to assume that the teaching and learning process is directed toward producing students who, through their own activity, come to share established scientific knowledge' (Eisenhart et al. 1996, p. 278). Accordingly, a balance was maintained between established but implicit conceptions of knowledge in terms of scientific content and then-popular and explicitly adopted conceptions of learning and knowing. Scientific literacy was not only defined in terms of individually constructed knowledge, but also in terms of more or less static scientific content 'possessed' by individuals.

Regarding the appropriation of the dynamics of science, such a perspective is problematic in at least two ways.

The first problem is that scientific literacy, despite being the result of a construction, is still defined as scientific content that can be contained by individuals. Inherently this perspective on knowledge still overshadows the conceptual content of science as knots and ties, that is, as containers of alliances, instruments, colleagues and other such elements that collectively make up the dynamics of science (see Fig. 68.2). Therefore, such a perspective on scientific literacy contributes to a context-concept dichotomy that is at odds with appropriation of the dynamics of science.

The second problem is that scientific literacy is not only defined as scientific content that can be contained by individuals, but also refers to scientific content as established and hence rather static scientific knowledge. This emphasis on scientific knowledge as a static and established entity also overshadows the content of science as containers of other flows that make up the dynamics of science (see Fig. 68.2). In addition, such an emphasis has led Morris Shamos (1995) to conclude that scientific literacy simply cannot be present among non-scientists. He argued that established scientific knowledge is too complex to be mastered by everyone, *just because it is scientific knowledge*. The desired level of scientific literacy required for mastering this knowledge, which he called 'true scientific literacy', is such that 'the individual actually knows something about the overall scientific enterprise' (Shamos 1995, p. 89). According to Shamos, this level is inaccessible to the majority of the citizenry. Scientific literacy defined in terms of scientific content is thus at odds with the idea of scientific literacy as prerequisite for *all* citizens in a scientifically sophisticated society. These paradoxical consequences of defining scientific literacy in terms of individual and static conceptions of knowledge have led science educators to rethink the concept.

Scientific Literacy as an Emergent Feature of Collective Human Activity

In the 1990s, Margaret Eisenhart, Elizabeth Finkel and Scott Marion started to rethink the concept of scientific literacy by starting from its broad aim of 'producing citizens who can use science responsibly and including more people in science' (Eisenhart et al. 1996, p. 268). A fundamental incommensurability was observed with scientific literacy defined in terms of scientific content. Specifically, there was doubt that the individual 'acquisition' of scientific content would lead to a citizenry who will use science responsibly in their daily lives or profession.

One important argument against this assumption draws on studies of speech practices inside and outside of schools. Such studies suggest that academic science discourse privileged in school science actually might discourage socially helpful and responsible uses of science in situations that students could encounter in daily life and future professions. In addition, inherent to conventions of scientific discourse is the privileging of particular voices (Eisenhart and Finkel 1998). Relationships exist between knowledge and the power structures that privilege the particular voices and hands who articulate, construct and thus constitute such knowledge. Framing scientific literacy in terms of scientific concepts and methods thus facilitates speech genres and modes of action that are constitutive for and preferred by conventional science. Accordingly, the privileged way of knowing and doing is the common scientists' way, which largely exhibits white middle-class and male epistemologies. Minorities and women are therefore often discouraged from doing science or from moving into science careers.

Another argument against the assumption that individual 'acquisition' of science is congruent with the broad aim of scientific literacy is provided by Wolff-Michael Roth and Angela Calabrese Barton (2004). They argued that the specialised knowledge that is found in curriculum reform documents is both inaccessible by direct experience and irrelevant in the majority of people's daily lives. Also, there is little evidence that knowing school-like facts and basic skills contributes anything to competent functioning in the everyday world. On the contrary, ample evidence from studies of the use of mathematics in daily life suggests that there is no relationship between what is taught in schools and levels of performance in everyday mathematical tasks.

In other words, there is no reason to believe that the individual 'acquisition' of scientific content leads to the citizenry using science responsibly in their daily lives or professions. In this regard, science educators rethought conceptions of knowledge in order to define scientific literacy in a way that would be congruent with its broad aims.

As discussed in the previous section, the dominant focus on knowledge as an individual cognitive entity is rooted in particular readings of constructivism. Such frameworks fail to emphasise the wider activities associated with school science (such as schooling, science and work) which go beyond the individual. To overcome this limitation, therefore, scientific literacy was rethought from cultural-historical frameworks that appropriate such wider activities. Thus, what 'constitutes "knowledge" at a given moment or across a range of situations is a matter of analysis, which has to take account of the motivations, interests, relations of power, goals and contingencies that shape the activity' (Roth 2003, p. 17). Hence the idea emerged that scientific literacy can be perceived as an emergent feature of collective human activity.

Human activity is composed of 'many, often dissimilar and contradictory elements, lives, experiences, and voices and discontinuous, fractured and non-linear relationships between these elements, lives, experiences, and voices' (Roth 2003, pp. 17–18). What ultimately counts as 'scientific literacy' can therefore only be understood by analysis of these systems, that is, by examining the manifold and interdependent means (speech, texts, tools, actions) by which knowledge is produced and hence distributed over and situated in collective human activity. 'Emergent', then, refers to the interdependent relationship in the evolving setting that, at certain points, exhibits specific characteristics such as scientific literacy.

From the perspective of collective human activity, knowledge is collective and distributed over the activity. For instance, in one case study of school science, students were asked by a local organisation to restore a pond located on their property that was in poor health, stagnant and smelly (Eisenhart et al. 1996). In response, they developed a restoration plan and this work required the students to situate their tasks in the local community, establish relationships with experts and community members beyond the school, and develop ways of talking and writing that were useful and persuasive in a real-world setting. Here, scientific literacy emerged as the students collectively cultivated understandings of scientific concepts and ideas that were both locally useful and technically sophisticated.

In another case study of science in a rural community, citizens interacted with scientists during an environment-oriented open-house event centred around a dispute over local water resources (Roth and Lee 2002). This case study showed that, collectively, more advanced forms of scientific literacy can be produced than for any individual (including scientists). For instance, the citizens questioned a scientist about the methodology that he used, which turned out to fall short for the problem at hand. Here, scientific literacy cannot be explained as individual, discrete and testable knowledge. In such terms, both citizens' questioning and scientists' inadequate responses would be understood as a lack of understanding of appropriate scientific methods. As collective activity, however, scientific literacy can be understood as an emergent feature of the collective human activity of both scientists and students. In this case, the scientist is not longer privileged as the one who defines what the scientifically literate citizen 'needs'. Nor is knowledge something that is 'used' by citizens in a scientifically sophisticated society. Rather, citizens and scientists collectively produce the scientific knowledge that is constitutive for the emerging scientific literacy which, in turn, contributes to a scientifically sophisticated society.

Definitions of scientific literacy that frame knowledge as collective human activity appropriate the dynamics of science in several respects. According to this frame, scientific content is not defined as something that is contained by individuals, but as tools in human activity. Because tools are dialectically linked with the wider activity in which they are used, they can be thought of as being inextricably bound up with and hence keeping together other aspects of activity, such as the human subjects using these tools, the communities in which they are used, and the specific rules that are associated with tool use. Hence, scientific content relationally contains the other elements of human activity rather than being fully contained by the individual human subject that is also part of this practice. In this way, scientific content is thought similarly to the knots and links that make up in part the dynamics of science (see Fig. 68.1). Moreover, when scientific content is understood dialectically as knots and links that keep together the other aspects of collective human activity, it can only be thought of as relational with the context which it shapes and by which it is shaped. Indeed, perceived from a perspective of knowledge as collective human activity, scientific content is part of this context. When scientific literacy is thought of as an emergent feature of collective human activity, it cannot overshadow the knots and ties that keep together alliances, instruments, colleagues and other such elements that collectively make up the dynamics of science (see Fig. 68.2).

Coda

Defined as an emergent feature of collective human activity, scientific literacy appropriates the dynamics of science because it provides the tools to exemplify conceptual elements as links and knots (i.e. containers) and not as something contained. In addition, it allows one to distinguish how the links and knots contain and hold together the dynamic aspects that shape and are shaped by the 'context' of science, such as instruments, autonomisation, alliances and public representation. How could we envision science education from this perspective?

Thinking in terms of activity implies that scientific literacy cannot be considered apart from the activities in which students engage. Hence scientific literacy emerges in those activities that bear considerable resemblance to the activities that produce scientific knowledge. Two examples of such activities in which students engaged have been illustrated previously. The key issue with respect to the emergence of scientific literacy is the extent to which students engage meaningfully in such activities and hence develop competent participation.

Currently, schooling does not give students many opportunities to develop competent participation in activities that bear considerable resemblance with the activities that produce scientific knowledge. This is because schooling activities are supposed to unfold in particular predetermined ways that lead students to 'mastering' specific scientific 'content'. Accordingly, in school science, scientific literacy is commonly defined in terms of scientific content that is supposed to be contained by individual students rather than a container that holds together the dynamic flows of science. Moreover, in terms of collective human activity, students are withheld from the agency by which they can exert the power over the elements that collectively determine how the activity unfolds. For instance, students are usually not allowed to participate in setting the goals and objects of their activities, choose tools, determine the division of labour or participate in constructing the rules. The result is that, rather than collectively becoming scientific literate, students become literate in meeting the aims of the schooling activity, namely, getting high grades. Students engage in a form of learning which Klaus Holzkamp (1993) has called *defensive learning* – a form of learning that has the function to avoid punishment.

In contrast, to engage meaningfully and hence develop competent participation in knowledge-producing activities in science, students should be given the agency to co-determine the way in which such activities unfold over time. In a science education envisioned from this perspective, the emerging scientific literacy appropriates the dynamics of science. Indeed, agency allows students to participate in setting the goals and objects of their activities, choose tools, determine the division of labour or construct the rules. In other words, it allows students to develop competent participation in keeping these activities running and to find allies, design instruments, mobilise the world and so on. Furthermore, agency allows students to develop and hence understand how particular elements of knowledge-producing activities in science, such as rules, objects and tools, are used as knots and links in holding together the dynamic flows of these activities. In short, agency over knowledge-producing activities in science allows students to experience collectively how 'methods', 'instruments' and 'concepts' emerge as knots and links containing the dynamic flows of science. In such a science education, students collectively learn to produce the knowledge that they will require as citizens in a scientifically and technologically sophisticated society of tomorrow.

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Chapter 69
Nature of Science in Science Education: Toward a Coherent Framework for Synergistic Research and Development

Fouad Abd-El-Khalick

The centrality of nature of science (NOS) to precollege science education cannot be overstated. NOS has been, and continues to be accorded a central position among the few major themes that cut across reform documents in science education around the globe both past (Robinson 1965) and present (Millar and Osborne 1998). Vigorous emphasis on helping learners develop informed understandings of NOS dates back to the 1950s (Wilson 1954). Since then, such emphasis has been accompanied by intensive lines of research that targeted assessing students' and teachers' views of NOS (see Driver et al. 1996; Lederman et al. 1998), developing and investigating curricular materials and pedagogical approaches to help students (see Lederman 1992; Meichtry 1993) and teachers (see Abd-El-Khalick and Lederman 2000) internalize more accurate understandings of NOS, and investigating factors and approaches mediating and facilitating the translation of teachers' understandings of NOS into classroom practice. These research and development efforts, no doubt, resulted in some progress. However, much remains to be done. Recent studies indicate that, around the globe, elementary (Khishfe and Abd-El-Khalick 2002), middle (Kang et al. 2005), high school (Dogan and Abd-El-Khalick 2008), and college students (Ibrahim et al. 2009), as well as teachers (Dogan and Abd-El-Khalick 2008) continue to ascribe to naïve views of NOS. What is more, pre-service and in-service science teachers holding informed views of NOS continue to struggle with integrating and enacting these views in their instructional practice, and consequently with helping their students achieve the desired understandings of NOS (Abd-El-Khalick and Akerson 2004). Progress to date remains frustratingly mismatched with the longevity and intensity of the

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research and development efforts dedicated to teaching and learning about NOS in science education.

Obviously, a host of factors underlies the current state of affairs. These include the well-documented complexities associated with bringing about significant and systemic change to the beliefs and practices inherent to science teaching and learning, science teacher education, schools and schooling, and educational systems and processes. Making headway with an especially challenging domain, such as teaching and learning about NOS, necessitates synergistic, long-term research and development efforts. While these efforts should be pluralistic rather than single-minded, they nonetheless need to draw on a coherent broad framework. Such a framework makes discourse, discord, and collaboration among researchers possible and allows them to dissect, critique, and build on each others' work rather than talk and work past each other. I believe that such a framework has been, and continues to be, wanting because of a lack of clarity about the nature of the construct of NOS. In particular, I believe that discourse, research, and development related to NOS in science education have been guided by two broad, mostly confounded, perspectives which I label here as the "lived" and "reflective" perspectives on NOS. The result has been bifurcated research and development efforts that, at best, lack synergy and, at worst, seriously hamper progress within the field.

The present chapter aims to explicate the assumptions underlying the two perspectives, and examine their implications for research and development efforts related to teaching and learning about, as well as assessing conceptions of, NOS. In so doing, the chapter takes a significant step toward outlining a framework that could foster synergy within the field and help advance both research and development efforts related to NOS in science education.

First Things First: What Science? And Whose NOS?

The lived and reflective perspectives are not related to the often invoked questions about "What science?" (cf. Cobern and Loving 2000), that is, claims about what counts as science from multicultural perspectives in contrast to more universalist conceptions of the scientific endeavor. Nor are the two perspectives related to questions about "Whose NOS?" (cf. Alters 1997), that is, the often invoked discords about NOS derived from philosophical, historical, and sociological studies of science. Instead, the lived and reflective perspectives derive from our conceptualization as a community of the nature of the construct of NOS. However, before proceeding to examine the two perspectives, I address the questions of what science and whose NOS because answers to these questions are crucial components to any framework that aims to guide research and development on NOS in science education.

The What Science Question: A Gentle Reminder About Our Charge and Mission

A concern that is often raised in relation to conceptualizing NOS derives from the question of what science serves as the frame of reference. The question generally leads to discussions about Western or universal science versus multicultural science or indigenous knowledge, and associated arguments as to the hegemony of the former and the need to address the latter in science education (Atwater 1993), including making provisions for multicultural science or indigenous knowledge in the science curriculum. Cobern and Loving (2000, p. 50) conducted a comprehensive and fair-minded analysis of this question and concluded that:

> Although one may hate to use the word hegemony, Western science would co-opt and dominate indigenous knowledge if it were incorporated as science. Therefore, indigenous knowledge is better off as a different kind of knowledge that can be valued for its own merits.

Irrespective of the merits of arguments for or against multicultural science or indigenous knowledge, the mission and charge of science educators do not include deciding what is and is not science, even though they need to be profoundly and critically cognizant of the bases that underlie such decisions. In this era of big science (Nye 1996), the academy, scientific community, and scientific establishment largely determine what counts and does not count as science. Such determination takes several forms ranging from explicit position statements, such as the position in the United States of the National Academy of Science (1998) on creation science, to endorsements in the form of providing or withholding funding (e.g., through the National Science Foundation in the United States and similar establishments in other nations), to the creation of new disciplinary positions and departments at research universities.

I believe that the charge for the science education community is to educate all learners and the general public about science that is sanctioned by the academy and the establishment. The functional term here being to educate, as compared to indoctrinate. Education entails helping all learners and citizens develop the understandings, skills, attitudes, and habits of mind–with special attention to the development of a critical stance toward, and healthy skepticism about, science itself–that would allow them to make sense of and utilize science to lead more fulfilling lives, make informed decisions about science-related personal and social issues, pursue a host of science-related careers, and meaningfully participate in cultural discourse championing or disputing science. In this regard, if science educators decide to make the question of what science their primary business, they might find themselves going down some slippery slopes (Loving 1997). For example, it could be argued that creation science is one form of indigenous knowledge endorsed by a group of individuals who are both alienated and marginalized by Western science. Thus, the argument would continue, creation science deserves a place in the science curriculum at par with other indigenous sciences!

It cannot be overemphasized that the present argument does not entail that the notion and implications of multicultural science or indigenous knowledge and related research efforts are insignificant or irrelevant to science education. On the contrary, as long as care is taken to not conflate issues of curriculum with ones related to pedagogy, such research would contribute tremendously to science education. For instance, research on indigenous knowledge could inform the development of pedagogical approaches and instructional materials that would empower students to successfully cross the borders between their cultures and the culture of science (cf. Aikenhead and Jegede 1999), make the transition between their life-worlds and that of school science (cf. Costa 1995), or even negotiate the assumptions underlying their worldviews and a scientifically compatible worldview (cf. Cobern 1996). What should be avoided are work and lines of argument that entail the provision of equal time to universal science and indigenous knowledge in the school science curriculum.

The Whose NOS Question: Beyond Pragmatic Irrelevance for Precollege Science Education

Some researchers argue that NOS remains a largely contested area, so much so that discourse, research, and development related to NOS in science education are not altogether plausible (Alters 1997). To be sure, philosophers, historians, and sociologists of science continue to disagree on a number of important aspects of NOS. Such disagreements include, for example, the continuing debates between empiricists (e.g., Van Fraassen 1998) and realists (e.g., Musgrave 1998) as to the ontological status of scientific theories and the entities they often postulate. To be sure, these disagreements about the content of NOS are relevant and need to be meaningfully addressed in any framework that aims to guide synergistic research and development efforts. In essence, what is at issue here is the question of benchmarking views of NOS; that is, deciding what counts as accurate or informed, and what counts as inaccurate or naïve views of NOS. It could be seen that this issue has serious implications for assessing learners' views of NOS, as well as the development of curricula and instructional materials designed to help learners internalize informed or accurate NOS understandings as stipulated in science education reform documents (e.g., American Association for the Advancement of Science [AAAS] 1990).

Two approaches have been used to address the question of benchmarking views of NOS. The first is more negative in its content and implications: It leverages disagreements among philosophers, historians, and sociologists of science as a basis for the implausibility of any benchmarking (e.g., Alters 1997) and, consequently, for questioning the meaningfulness of the notion of teaching and learning about NOS. This approach was heavily criticized for exaggerating disagreements while simultaneously disregarding substantial agreement with regard to some central NOS issues (Smith et al. 1997). The second approach adopted the opposite position, that is, highlighting agreements among philosophers, historians, and sociologists while downplaying, or remaining silent on, continuing controversies. The latter approach is more positive in its content and implications. Indeed, this approach underlies the very development of statements on NOS adopted by reform documents in science education. This approach is most evident in documents, such as *Science for All Americans* (AAAS 1990), where, for example, the aforementioned debates between realists and empiricists were completely disregarded. In other instances, contentious issues were addressed by adopting compromise positions, such as affirming that scientific knowledge is tentative but durable (AAAS 1990, pp. 2–3), which seemingly is an attempt to veer away from realist perspectives on the status of scientific knowledge while simultaneously acknowledging that successes in science cannot simply be explained by social constructivist conceptions of NOS (Brown 1998).

The second approach, which has proven fruitful for guiding a host of research and development efforts, relies on arguments that are pragmatic in nature. One such argument, which we put forth about a decade ago (Abd-El-Khalick et al. 1998), goes something like this: Disagreement on specific conceptualizations of NOS should not be surprising given the multifaceted and complex nature of the scientific enterprise. Also, similar to scientific knowledge, conceptions of NOS are tentative and dynamic: they have changed (and continue to change) throughout the development of science and systematic thinking about its nature and workings (Abd-El-Khalick and Lederman 2000). Nonetheless, at one point in time and at a certain level of generality, there is a shared wisdom (even though no complete agreement) about NOS amongst philosophers, historians, and sociologists of science. For example, presently it is very difficult to reject the theory-laden nature of observation and investigation, or to defend a deterministic or absolute conception of NOS. In other words, a set of generalized, virtually non-controversial notions about NOS, which are relevant to the education of precollege students, could be identified and fruitfully guide research and development efforts in science education (e.g., Abd-El-Khalick et al. 1998). Such NOS aspects have been advanced in recent reform documents (e.g., AAAS 1990) and include, among other dimensions, that scientific knowledge is tentative (subject to change), empirical (based on and/or derived from observations of the natural world), theory-laden (impacted by scientists' theoretical positions and personal histories), creative (partially based on human inference, imagination, and creativity), and social (produced through collaborative and negotiated processes).

The crucial point to emphasize here is that, from a pragmatic perspective, even with these seemingly non-controversial aspects of NOS, much remains to be desired in precollege science classrooms. Students and teachers still ascribe to naïve views of many aspects of NOS, such as a complete lack of appreciation for the social nature of the production and validation of scientific knowledge. Also, teachers continue to structure science instruction in ways, and science textbooks continue to convey images about science, that misrepresent NOS and explicitly communicate myths about its nature and workings. For instance, despite consensus on the theory-laden nature of observation and investigation (Gillies 1998), a large majority of students and science teachers continue to ascribe to naïve inductivist views of NOS. Many science teachers continue to engage their students in activities in which theory-free data are collected and supposedly analyzed. The same teachers continue to be disappointed and frustrated when students fail to discern the obvious patterns in these data that they want students to see, or draw the 'obvious' conclusions that the teachers want students to reach! Similarly, despite it being debunked by philosophers, historians, sociologists, and scientists alike (Bauer 1994), the myth of a universal, step-wise, prescriptive, Scientific Method continues to linger on in some form or another in science textbooks and laboratory manuals (Abd-El-Khalick et al. 2008), and to be posted in prominent places on the walls of science classrooms. Students and teachers continue to believe that scientific knowledge is actually generated and validated through the use of the Scientific Method. Many teachers continue to have students memorize the steps of this so-called method and force students to structure their thinking and activities in science along the rigid lines of this archaic notion.

Similarly, the nature and functions of scientific theories continue to be misconstrued by students and misrepresented by science teachers with discourse that is centered on proving and disproving theories rather than on issues of explanatory and predictive power, generative research potential, and internal consistency. The potentially undesirable consequences of these naïve ideas in propagating and deepening confusion about central issues, such as evolutionary theory versus creation science, are too well known to be reiterated here. What is more, despite the well-established and documented claims as to the centrality of critical social discourse to the generation and validation of scientific knowledge (Longino 1990), students continue to believe that scientists work in isolation and communicate finished products to their colleagues. By the same token, many science teachers continue to deprive students from opportunities to communicate, defend, negotiate, and restructure the ideas they generate in the context of science-based activities. Thus, it could be seen that our work is cut for us even after deciding to forgo—for pragmatic reasons—high-level philosophical, historical, and sociological controversies and limit ourselves to a rather small set of seemingly non-controversial notions about NOS of the sort endorsed in current science education reform documents.

Arguments based on the pragmatic irrelevance of high-level controversies about NOS to precollege science education are plausible and needed in an applied field like science education where teachers around the globe walk into science classrooms every day and convey images, mostly naïve ones, about NOS to their students. However, philosophical, historical, and sociological controversies cannot be dismissed altogether because, in essence, they represent the very content of the construct of NOS. I am afraid that the pragmatic underpinnings of the treatment of NOS in reform documents is either not understood or disregarded more often than not. The various aspects of NOS identified in such documents (e.g., AAAS 1990) or by researchers (e.g., Osborne et al. 2003) sometimes seem to be uncritically accepted as true of NOS. However, in the same way that it is inaccurate and intellectually dishonest to teach students, for example, that scientific knowledge is certain or that scientists are necessarily objective, it is equally problematic to convey the notions that scientific entities are merely social constructions or that scientists' theoretical biases always prevail in the face of evidence (e.g., Khishfe 2008; Pomeroy 1993). Philosophical and historical controversies convincingly show that the latter claims are, at least, contested. The fact of the matter is that seemingly simple aspects, such as the tentative or empirical NOS, are much more complex than is often construed by some researchers and educators engaged with this domain.

There is need to extend the current framework for benchmarking NOS, which focuses on some generalized NOS aspects and is made possible by highlighting philosophical, historical, and sociological agreements while dismissing discords. We need an alternative framework that remains faithful to the controversial nature of some NOS dimensions. At the same time we need to be careful to avoid the perils of dismissing the whole enterprise of NOS because of the noted controversies. We should not lose sight of the fact that science continues to be explicitly and gravely misrepresented in curricular materials and instructional practices. For example, we need to be aware that science textbooks are populated with a host of explicitly stated and didactically taught falsehoods about NOS, such as that, "A scientific law is simply a fact of nature that is observed so often that it becomes accepted as truth. The sun rises in the east each morning is a law of nature because people see that it is true every day" (Phillips et al. 1997, p. 59). This latter statement, it could be seen, presents a bundle of inaccuracies ranging from affirming the inductivist doctrine, to confusing scientific laws with empirical observations, to confirming the absolute nature of scientific knowledge, not to mention giving an outright false example of a scientific law. These are the images of NOS that we need to keep in mind when approaching curricular decisions about the inclusion of more accurate representations of science. Finally, we need to remain keenly mindful of the interests and abilities of our major audience, namely, precollege students.

One viable alternative would be to continue to focus on a set of NOS aspects that currently are emphasized in reform documents and enjoy wide support within the science education community (tentative, empirical, inferential, creative, theory-laden, and social NOS, etc.). These aspects, however, would be addressed at increasing levels of depth as learners move along the educational ladder from elementary school to college-level science teacher education programs. Thus, treatment of the target NOS aspects would span a continuum from general, simple, and unproblematic in elementary grades to specific, complex, and problematized (or controversial) in science teacher education settings, while taking learners' developmental levels into consideration. Additionally, the interrelatedness of these NOS aspects would be progressively examined with greater depth to provide learners with ample opportunities to construct, re-construct, and consolidate their own internally consistent frameworks about the epistemological foundations of science. Table 69.1 provides examples of addressing some NOS aspects under the proposed framework. It could be seen that the level of generality at which NOS aspects are addressed at one end of the continuum (i.e., the elementary level) render them non-controversial, but significantly more accurate than currently propagated myths about NOS. At the secondary level, learners would be expected to discuss aspects of NOS with reasonable levels of sophistication that go beyond superficial platitudes, such as that scientific

Table 69.1 Examples of addressing some aspects of NOS at progressive levels of depth along the educational ladder

Educational level	Examples of target NOS aspects: Tentative NOS	Theory-laden NOS	Empirical NOS	Social NOS	Level of depth
Teacher education	There are debates as to whether scientific knowledge grows by accretion (commensurable across theoretical frames) or through paradigmatic shifts (incommensurable across theoretical frames)	There are debates as to the nature and significance of the theory-ladenness of observation. Is theory ladenness significant beyond situations where the evidence lays at the very edge of the human perceptual apparatus and/or observational instruments?	Scientific theories are underdetermined by evidence. Debates continue about the extent to which rationality versus value judgment mediate the use of evidence in the process of theory choice in science	Debates continue about the viability of social constructionist conceptions in accounting for science's success in the absence of "realist" conceptions. Only "miracle" can explain such success if science was not getting closer to the "true" nature of phenomena!	Specific, complex, problematized (controversial)
Secondary school	Scientific knowledge is expanded, revised, or rejected because of two fundamental reasons: (1) New evidence is brought to bear [Empirical NOS], and/or (2) existing evidence is reinterpreted in light of theoretical advances [Theory-laden NOS]	Theories might determine what scientists "see" when conducting investigations through selective attention and/or influencing the interpretation of "raw" inputs from the environment.	The relationship between scientific knowledge and evidence is indirect. Theories can only be tested by comparing their consequences with empirical observations. Hypotheses do not "jump out" from evidence: Inference beyond the evidence is usually involved [Creative NOS] The relationship between knowledge claims and evidence is mediated by theory [Theory-laden NOS].	The social character of science contributes to its objectivity: Inter-subjective critical discourse through established value-driven channels (e.g., double-blind review procedures) minimizes the subjectivities of participant scientists.	

	Scientific knowledge changes in, at least, two fundamental ways: (1) It is expanded through accretion, and/or (2) discarded and altogether replaced with new knowledge.	Theories are crucial to conducting scientific investigations because theories enable scientists both to choose what evidence to collect (and what evidence to disregard) and how to interpret the collected evidence.		Science is conducted within the context of social institutions and has established and identifiable norms.	⇩
Elementary school	Scientific knowledge is subject to change over time	Scientific investigations always involve theories and empirical observations	Science demands evidence: Scientific knowledge is derived from and/or supported by observations of the natural world	Different groups of scientists contribute to the development of scientific knowledge	General, simple, unproblematic

Note. The treatment of these few NOS elements across the educational ladder is meant to be illustrative rather than exhaustive.

knowledge is tentative. On the other end of the continuum, it could be seen that science teachers would be tackling nuanced complexities about aspects of NOS, including the examination of current controversies among philosophers, historians, and sociologists of science. As a result, science teachers would be better positioned to not only support their students' learning about NOS, but to tailor the level of depth at which NOS is addressed to the specific interests and abilities of those students. Such an approach, it should be noted, is essentially not different from the way science content is currently addressed in various curricula. Consider, for example, the atomic structure and the progression of representations to which students are exposed: from a solar system model of the atom in elementary grades to probability distributions of electron clouds in undergraduate college studies. I believe that the proposed framework both addresses our pragmatic mission as science educators and remains faithful to the status of our knowledge about NOS. Obviously, working out the details of addressing various NOS aspects across the suggested continuum requires further work and research, especially in terms of understanding the developmental appropriateness of the various (often abstract and complex) NOS ideas.

Lived and Reflective Perspectives: Situating NOS

The lived and reflective perspectives are not related to the what science and whose NOS questions. Indeed, I believe advocates of both perspectives are in agreement about the aforementioned answers to these two questions. Differences between the two perspectives are subtle but have significant curricular and pedagogical implications for influencing and assessing learner conceptions of NOS. Advocates of the lived perspective (e.g., Kelly and Duschl 2002) assume that NOS is science or doing science. Thus, NOS is the practice of science. By comparison, advocates of the reflective perspective (e.g., Abd-El-Khalick and Lederman 2000) argue that NOS derives from reflecting on science, it is about the practice of science. The two perspectives lead to different ways of thinking and talking about NOS both among and between science education researchers and science teachers. Some examples might help to clarify the distinction. For instance, it took me a long time to realize that when discussing the so-called Scientific Method with colleagues and science teachers, we sometimes were actually talking past each other because we had different frames of reference in mind, namely, epistemology of science and practice of science. When I say, "There is no such thing as a universal Scientific Method," I am basically arguing that there is no guaranteed method (inductive, deductive, falsificationist, hypothetico-deductive, etc.) that would unerringly lead scientists to the development of valid claims about natural phenomena. When science teachers object to my claim—as they often do—they are usually saying that scientists actually practice the Scientific Method because they do experiments or conduct a set of activities in some set order or another (e.g., observing, making hypotheses, collecting and analyzing data, drawing conclusions, and communicating results). Also, when teachers agree with my claim about the myth of the Scientific Method, they are usually saying that scientists do not necessarily do their activities in a certain sequence but could start at different points and go back and forth among the various steps. Similarly, it took me a while to realize that when some science educators say they have addressed NOS instructionally in some intervention, they simply are referring to the fact that learners were engaged with doing inquiry-based science activities (e.g., McComas 1993).

While the lived and reflective perspectives are necessarily interrelated, they are not identical. At a more basic level, the distinction between the two perspectives is akin to the common conflation of the processes of science and inquiry skills with NOS. For example, the act of observing is a fundamental scientific process: Students and scientists develop varying levels of skill and proficiency in making observations and using various observational instruments. The notion of the theory-laden nature of observation, nonetheless, belongs to the domain of NOS. More importantly, engaging in observation does not necessarily lead the observer to discern or construct the notion of the theory-ladenness of observation. By the same token, students in a physics course can develop crucial inquiry skills, such as controlling variables, and designing and conducting experiments. Engaging these activities, however, does not entail that students would come to understand, for instance, the impossibility of having a crucial experiment in physics, that is, an experiment that conclusively adjudicates between two competing theories that purport to explain the same phenomenon (Duhem 1904–1905/1954). This latter notion belongs to the domain of reflecting on the activities of science, that is, the domain of NOS. Empirical evidence supports these conclusions (e.g., Schwartz et al. 2004). In this regard, a useful heuristic for distinguishing between (the necessarily interrelated) scientific inquiry and NOS is to think of the former as the set of actions undertaken to address foundational issues about theory of scientific method brought about by the latter. For example, the practice of double-blind experiments—the golden standard of investigating the effectiveness of medicinal drugs and treatments, is an established scientific inquiry procedure developed in response to a core epistemological dimension associated with the theory-laden nature of observation.

The question follows: What perspective is more viable, NOS is scientific practice or NOS is about scientific practice? One possible way to answer this question is to examine the enterprise we call NOS. NOS is a reflective endeavor: The varying images of science that have been constructed throughout the history of the scientific enterprise are, by and large, the result of the collective scholarship of historians, philosophers, and sociologists of science, as well as scientists turned historians or philosophers, and reflective scientists. Representations of the scientific enterprise reflect the collective efforts of these scholars to reconstruct the history, activities, and practice of science in an attempt to understand its workings and the nature of its products. When science educators approach NOS, they do not consult the published writings of practicing scientists. Rather they read and cite the works of philosophers, historians, and sociologists of science, including scientists turned historians or philosophers. To be sure, approaches to studying the scientific enterprise have undergone major shifts, such as from normative to more descriptive, from philosophically-minded histories to historically-minded philosophies, from upholding a firm distinction between the contexts of discovery and justification to blurring this distinction, from studies of polished scientific theory to the study of science-in-action, and from a sole focus on the physical sciences to examining the biological sciences. Nonetheless, the domain of NOS largely remains a field of scholarship for non-practicing scientists. Obviously, there are some active scientists who explicitly address and publish about epistemological issues (e.g., Weinberg 2001). These cases are, nonetheless, exceptions to the rule, and hardly derail the current argument because the overwhelming majority of practicing scientists do not have active research programs that address epistemology of science.

Indeed, as Kuhn (1970) argued, practicing scientists do not engage with reflective and re-constructive activities, and they mostly do not need to. Scientists are trained by apprenticeship in communities of practice that do not generally engage them, at least not consciously or explicitly, with epistemological issues. A quick survey of doctoral programs in various scientific disciplines would show that scientific education rarely includes, if ever, formal coursework in history, philosophy, or sociology of science. Indeed, such programs do not even include formal coursework in research methodology of the sort required of doctoral students in psychology or education. Kuhn (1970) argued that initiating science students into disciplinary traditions includes having them take the processes and methods of those disciplines, and consequently the underlying ontological and epistemological values and assumptions, for granted. Putting aside epistemological and ontological issues, and the conviction that the methods at hand will generate valid and reliable knowledge, advanced students and scientists can engage the activities of their science disciplines and invest the time and energy required to vigorously pursue answers or solutions to specific questions or problems related to some restricted aspect of a minute corner of the natural world. Epistemological and ontological underpinnings do not seem to be crucial to the learning or practice of disciplinary science (at least, according to Kuhn, in periods of "normal" science). For Kuhn, barring periods of intense crises, the very fact that practicing scientists do not tackle epistemological issues is an integral aspect of NOS.

Indeed, the scientist could very well be naïve on issues related to NOS. As Medawar (1969, p. 11) put it:

> Ask a scientist what he conceives the scientific method to be, and he will adopt an expression that is at once solemn and shifty-eyed: solemn, because he feels he ought to declare an opinion; shifty-eyed, because he is wondering how to conceal the fact that he has no opinion to declare. If taunted he would probably mumble something about "Induction" and "Establishing the Laws of Nature."

Scientists are practitioners within well established traditions of practice and cannot be assumed —as the evidence shows—to hold coherent epistemologies of the sort sought in philosophically-oriented inquiries, which underlie our conceptions of NOS (Yore et al. 2004). Thus, it could be seen that while scientific practice provides the context and stuff for investigating epistemological issues, the practice itself is not NOS. NOS is not lived practice. The endeavor to delineate various aspects of NOS is not necessarily a derivative of engaging the practice of science or going through its motions, but rather a matter of putting questions to and reflecting on that practice. NOS is reflection on practice.

Having made the distinction between the two perspectives, the following section explores its implications for influencing and assessing students' and teachers' conceptions of NOS. This examination will serve to show that, irrespective of one's inclination to champion the lived or reflective perspective, empirical evidence seems to weigh on the side of the latter.

Implications of the Lived and Reflective Perspectives

Implications for Influencing Learner Conceptions of NOS

The lived and reflective perspectives on NOS entail very different approaches to influencing students' and teachers' conceptions of NOS. Elsewhere we dubbed these approaches as implicit and explicit approaches, respectively, to teaching about NOS (Abd-El-Khalick and Lederman 2000). From a lived perspective, NOS is practice and can only be acquired implicitly through practice. As Duschl put it, "NOS… cannot be taught directly, rather it is learned, like language, by being part of a culture" (Duschl 2004, as cited in Abd-El-Khalick et al. 2004, p. 412). The lived perspective assumes that precollege students can actually engage in authentic scientific activities akin to those engaged by practicing scientists. Abd-El-Khalick (2008) and Burbules and Linn (1991) explicate the shortcomings of this assumption. Advocates of the lived perspective and implicit approach also assume that learning about NOS would result as a "by-product" of learners' engagement in science-based activities. For example, Barufaldi et al. (1977, p. 291) noted, "Students presented with numerous hands-on, activity-centered, inquiry-oriented science experiences… should have developed a more tentative view of science." Similarly, under the implicit approach, changes in the learning environment are believed to promote learners' understandings of NOS. For instance, Haukoos and Penick (1983, p. 631) noted that if "the instructor assumed a low profile by sitting at student eye level and stimulated discussion of the… materials with questions designed to elicit student ideas" then learners would develop an understanding of the notion that scientific knowledge is not complete or absolute.

By comparison, from a reflective perspective, NOS is about practice and draws on a cognitive body of scholarship that examines scientific practice from a distance. Thus, NOS cannot be learned automatically or implicitly through engagement in doing science, but should rather be consciously addressed as part of the science curriculum through structured reflection on practice, which draws on conceptual tools available in the body of scholarship that we refer to as NOS. Thus, advocates of an explicit approach argue that the goal of enhancing learners' conceptions of NOS "should be planned for instead of being anticipated as a side effect or secondary product" of engagement with science (Akindehin 1988, p. 73). A variety of approaches have been developed under the explicit approach, including the use of history and philosophy of science and explicit reflective NOS instruction to address students' and teachers' NOS views.

If one accepts the argument developed earlier about the very nature of the NOS enterprise, one would conclude that the lived or implicit approach to influencing students' and teachers' NOS views would not be very effective. Of course, the argument could be debated. However, the relative effectiveness of implicit and explicit approaches to NOS instruction could be adjudicated by reference to empirical evidence. First, much of the curricula of the 1960s and 1970s emphasized hands-on, inquiry activities. These curricula assumed that NOS would be learned implicitly through doing science as opposed to requiring explicit attention. However, research studies that focused on the effectiveness of these curricula have consistently indicated that students did not develop the desired NOS understandings (e.g., Tamir 1972). Second, a critical review of the literature shows that explicit approaches were more effective than implicit ones in bringing about substantial changes in science teachers' views of the scientific enterprise (Abd-El-Khalick and Lederman 2000). Thus, empirical evidence does not support the effectiveness of approaches to influencing views of NOS derived from the lived perspective.

Implications for Assessing Learner Conceptions of NOS

The lived perspective entails assessing learners' NOS conceptions from practice, that is, while students are engaged in doing science (Kelly et al. 1998). Irrespective of the form that such an assessment would take, it will involve an inference to beliefs from actions. This approach is apt to be problematic. As noted above, practicing scientists do not necessarily do science in accordance with an articulated epistemological framework; such a framework is rarely explicated in scientific apprenticeships. While scientists' actions might be consistent with an epistemological framework underlying the disciplinary tradition into which they were initiated, these actions might not tell much about a particular scientist's underlying epistemological beliefs. For example, a friend of mine is a computational chemist heavily engaged in university-based pharmaceutical research in which she builds virtual macro-molecules and investigates their stability and interactional properties with certain parts of virtual receptors on cellular surfaces. She is also a devout Christian. In a casual conversation, she indicated that taking communion from the same utensil during Sunday mass cannot result in the spread of orally-transmitted viruses among worshipers because God would not allow such a thing to happen to those engaged in such a holly deed. This is an example of a scientist who believes in supernatural intervention in the course of an established and well understood natural phenomenon, that is, the spread of infectious agents. Many of us can reproduce similar examples in which some scientist's beliefs are not consistent with their daily scientific practice and associated worldview.

Thus, it could be seen that assessments involving inferences to beliefs from actions are based on the shaky assumption that learners' action as they engage in doing science are necessarily reflective of, and consistent with, an underlying epistemological framework. What makes this approach even trickier is the mounting evidence, which indicates that students' epistemological beliefs are fluid, contextual, fragmented, and even outright inconsistent (e.g., Jon Leach et al. 2000). Additionally, like other assessment approaches to epistemological beliefs, inferences to beliefs from actions run the risk of imposing the observer's own epistemological framework on those observed (i.e., creating versus assessing students' conceptions of NOS). One possible result is attributing some coherent framework (e.g., inductivist, hypothetico-deductivist) to students not because they necessarily ascribe to such a framework, but because the observer approaches the task with a number of coherent frameworks in mind (this is the theory-laden nature of observation in action!). This situation is akin to convergent NOS assessment instruments that often indicated that students held some consistent epistemological framework, which later turned out to be a mere artifact of the fact that these instruments were designed with specific epistemological frames in mind (Aikenhead 1988). Of course, approaches using inferences to beliefs from actions could ameliorate this latter concern by having several observers independently examine and compare student practices across several contexts. Still, this assessment approach needs further anchorage. This anchorage, I believe, amounts to engaging students in reflective discourse about their actions and conceptions of NOS.

The reflective perspective on NOS entails that students be engaged in reflective discourse regarding their images of science or beliefs about NOS. This approach has several advantages. First, the issue of whether the approach itself is assessing or creating students' views of NOS is irrelevant because this perspective does not assume that students have well articulated and consistent views of NOS. Rather, the reflective approach assumes that learners' views of NOS are, at best tacit, fragmented, and inarticulate. These views are brought to the forefront, examined and even revised through structured reflection over the course of the assessment in the same way that philosophers, historians, and sociologists of science engage in structured efforts to reconstruct the practice of science to bring aspects of NOS to our attention. Second, by engaging learners in discourse, assessors could follow their lines of thinking and clarify any ambiguities in their statements. While inference is necessarily involved, it is minimized. Assessors could test their inferences about learners' NOS views on-the-spot through continued discourse. Third, assessors could explore the degree to which learners' views are consistent through triangulation: A certain aspect of NOS could be assessed using a variety of prompts and by reference to several contexts. Our approach (Lederman et al. 2002) provides one possible form for assessing NOS conceptions from the reflective perspective.

Of course, one shortcoming of the reflective approach is the extent to which learners and assessors know and are familiar with the contexts in which the views about NOS are elicited and will necessarily be anchored. This could provide a useful juncture to meaningfully link both approaches to the assessment of NOS views: Students could be engaged in reflective discourse about their own practice and the ideas they construct instead of reference to the practice of scientists and canonical scientific knowledge. However, there are, at least, two disadvantages to such an approach. First, as the contexts invoked for reflection are apt to be very idiosyncratic, cross-study comparisons would be difficult. Second, some attributes of NOS can hardly be situated in short-lived science-related student practice. These aspects include, for example, the nature of scientific theory and law, and the tentativeness of scientific claims, which become apparent through examination of relatively long periods in the history of science.

It should be noted that the reflective perspective on NOS entails that engaging learners with authentic scientific practice and inquiry activities provides the ideal context for influencing and assessing their NOS views. However, while necessary, this engagement is not sufficient. Engagement needs to be coupled with reflection. This is somewhat different from the consequences of the lived perspective, in which engagement with authentic scientific practice and activities is teaching about, and assessment of, NOS.

A Developmental Explicit-Reflective Framework for Addressing NOS in Science Education

Several crucial components of the proposed framework have already been outlined above. These components include, first, conceptualizing NOS as a reflective endeavor. NOS embodies a cognitive body of works representing the collective efforts of scholars engaged with the systematic study of science from—among other lenses—philosophical, historical, and sociological lenses. Thus, while focused on scientific practice, NOS cannot be reduced to practice. Teaching and learning about NOS in science classrooms entail internalizing understandings about science derived from this body of scholarship. Second, the framework extends the approach underlying current reform documents in science education, which highlights generalized agreements about NOS and disregards controversial areas. This is achieved by focusing on currently emphasized aspects of NOS that are, nonetheless, addressed at increasing levels of depth along a developmental continuum from a treatment that is general, simple, and unproblematic at the elementary school level to one that is specific, complex, and problematized (or controversial) in science teacher education settings (see Table 69.1). Such an approach addresses the pragmatic need to present precollege students with more accurate conceptions of NOS while remaining faithful to the current status of our understandings about NOS. The implications of the framework for influencing and assessing learner conceptions of NOS have also been touched upon. In particular, the importance of the generative nature of NOS assessments and the issues underlying assessment approaches that purport to make inferences from practice to beliefs about NOS were discussed. Additionally, the proposed framework entails an explicit-reflective approach to addressing NOS instructionally in science classrooms. Some brief comments about this latter approach are in order.

An explicit-reflective approach to NOS instruction should not be equated or confused with didactic instruction. The explicit-reflective approach, first introduced by Abd-El-Khalick et al. (1998) and then expanded and refined (e.g., Abd-El-Khalick 2001, 2005), represents an overarching framework to help guide instruction about NOS.

The label "explicit" is curricular in nature, while the label "reflective" has instructional implications.

Thus, far from referring to direct or other modes of didactic instruction, the label explicit emphasizes the need for including specific NOS learning outcomes in any instructional sequence aimed at promoting NOS understandings. As is the case with learning about science content or developing science process skills, learning about NOS should be intentionally planned. The inclusion of specific NOS learning outcomes in curricula does not entail a specific instructional approach, be it direct or inquiry-oriented. Science curricula and instructional materials put forth specific learning outcomes related to complex scientific theories, principles, and ideas that, nonetheless, end up being addressed using a range of pedagogical approaches including those that are active, student-centered, collaborative, and/or inquiry-oriented in nature. Choosing a specific pedagogical approach often depends on a number of factors, including the instructional outcomes themselves; the characteristics, abilities, interests, and skills of the learners; available resources; and the educational milieu. Our strong preference would be for choosing pedagogical approaches that are active, student-centered, and collaborative in nature, as well as embedded in science content and authentic inquiry-oriented experiences (e.g., Abd-El-Khalick 2001).

The reflective component, nonetheless, does entail instructional elements to be incorporated into pedagogical approaches undertaken from within the explicit-reflective approach. There is need for the provision of structured opportunities designed to encourage learners to examine their science learning experiences from within a NOS framework. This latter framework would focus on questions related to the development and validation, as well as the characteristics of, scientific knowledge. In our own work, this reflective component had often taken the form of questions or prompts embedded within science learning activities (e.g., Khishfe and Abd-El-Khalick 2002), as well as synthesis activities, such as writing reflection papers in response to specific NOS-related cues (e.g., Abd-El-Khalick 2005).

A final and significant question remains: Can the lived and reflective perspectives be reconciled to work in synergy? I believe yes. Researchers working within these two perspectives could capitalize on and benefit from each others' work if the subtle, though significant, difference in perspective is worked out through continued discourse. As emphasized above, engagement with authentic science or inquiry-based activities is not sufficient for learning, or assessing learner views, about NOS. Nonetheless, such engagement is necessary. This component is crucial to achieving synergy between the two perspectives. Advocates of the lived perspective need to realize that while their approach fosters the development of crucial content understandings, inquiry skills, and habits of mind, they fall short of actually addressing NOS because the critical component of reflection on practice is wanting. Similarly, they need to realize that making inferences about learner conceptions of NOS from practice without additional anchorage in generative forms of learner discourse entails significant threats to the validity of the assessments. By the same token, those who attempt to address NOS explicitly without meaningfully embedding their approach in science content and/or authentic science inquiries will most likely fail to convey to students more than superficial platitudes about the characteristics of scientific knowledge and the assumptions underlying its development. Similarly, generative assessments of learner views of NOS that are not anchored in specific science content or inquiry contexts will also suffer validity issues resulting from difficulties of interpreting learner responses that are necessarily contextual. If these mutual understandings are achieved, then we can significantly advance research and development efforts related to NOS. This is especially the case because significant questions remain to be answered in relation to, among many other things, the developmental appropriateness of the target NOS aspects for precollege students and their implications for the aforementioned developmental approach to addressing NOS aspects, effective ways to embed NOS in science content instruction and inquiry activities, developing science teachers' pedagogical content knowledge for teaching about NOS, helping teachers negotiate a host of mediating factors that seem to impede their implementation of science instruction that is consistent with what we know about NOS, and the relationship between learners' views of NOS and their learning of science content and engagement with inquiry activities.

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Part VIII
Out-of-School Learning

Chapter 70
Lifelong Science Learning for Adults: The Role of Free-Choice Experiences

John H. Falk and Lynn D. Dierking

The nature of science learning is changing worldwide as individuals have unprecedented access to science education opportunities from cradle to grave, 24/7, through an ever-growing network of educational opportunities beyond schooling which include visits to museums, zoos, aquariums, science centers, natural area parks and reserves, television, radio, films, books and magazines, and increasingly through personal games, podcasts, the Internet, and other social networking media (Falk and Dierking 2002). A hallmark of this revolution in science learning is that collectively these organizations and tools enable a growing number of individuals to customize and take charge of their own learning. This is particularly the case for many adults who are no longer engaged in formal schooling.

Adults engage in science learning every day and across their adult lives – at home, at work, and while out in the community; much of this learning is free-choice learning. We chose this as the focus of our chapter because the companion pieces in this section of the volume primarily focus on school-aged children. This chapter provides a framework for understanding how adult nonschool experiences contribute to a person's ability to stay aware, informed, and engaged in lifelong science learning.

However, before we proceed we should clarify one aspect of our terminology. We coined the term free-choice learning more than 10 years ago in order to capture the essential nature of this paradigm shift in learning – a recognition that people learn every day throughout their lives, but also that learning is first and foremost a learner-centered, not an institution-centered phenomenon. Free-choice learning describes the nonlinear, self-directed learning that occurs when individuals have primary responsibility for determining the what, when, where, how, why, and with whom of learning. Although the term free-choice learning does not define the *where* of learning entirely, currently most free-choice learning occurs outside of the formal education system.

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Adult Learners

A striking characteristic of much of the research on science learning has been the almost singular focus on children's learning; in particular children's school-based learning. The vast majority of a person's lifetime is spent as an adult and even the childhood years are not exclusively given over to schooling. By the age of 18 the average child will have spent only about 20% of his or her waking hours in a classroom and the average person over the course of a lifetime will spend considerably less than 10% engaged in schooling (Sosniak 2001). This would suggest that much, perhaps even most science learning occurs outside of school and beyond the years of childhood. Recent investigations by Falk, Storksdieck, and Dierking (2007) support the view that the majority of science learning occurs outside of school classrooms. In fact, adults attribute roughly half of their science learning to free-choice learning experiences (Falk et al. 2007). Although in the online environment, research suggests that the factors that motivate older learners are not substantially different from those of younger ones (Rockman et al. 2007), it has long been appreciated that the learning needs of adults, in science or other areas, differ from those of children, and of course vary as a function of the individual and change with life needs across the lifespan (UNESCO 1997). Despite individual differences though, it is possible to define a set of learning goals that are fairly typical of adult learners (Falk and Dierking 2002). Adults seek:

1. Increased opportunities to fill discretionary time, build identity, and begin establishing intimate relationships
2. A desire to improve oneself, either personally or professionally
3. A desire, and increasingly the time, to pursue hobbies and continue learning in personally meaningful ways
4. A desire to achieve mastery
5. A desire to become a mentor and share what one knows with others

All of these learning goals can and are met through free-choice learning.

In fact, adult learning outside of formal contexts such as classrooms and training facilities is much more important and pervasive than was typically assumed. David Livingstone (1999, p. 49) compares free-choice learning to an iceberg: "mostly invisible at the surface and immense in its mostly submerged informal aspects." A recent survey of Canadian adults found that over 95% of these adults were involved in some form of explicit free-choice learning activity that they considered important. Compared to comparable data collected a generation earlier, adults increased the amount of free time devoted to learning by more than 50%, typically dedicating an average of approximately 15 h per week to free-choice learning. For many adults, enhanced understanding of science and technology represents an important part of the free-choice learning they engage in during their adult life.

Research on Adult Free-Choice Learning

Although free-choice learning has been engaged in for as long as there have been humans, investigations of adult learning outside the classroom or laboratory have only occurred quite recently. Exacerbating the paucity of this research is the fact that what little research has been conducted, is often scattered across many disciplines and subdisciplines, with few efforts to consolidate, situate, and synthesize it within an overall framework. However, today there is a growing body of research investigating the "how, where, when, why, and with whom" of science learning in and from informal environments, both physical and virtual. Much of this research is still focused exclusively on children but there is growing awareness that investigating adult learning is important also. These investigations tend to fall into one of three, essentially independent lines of inquiry: (a) investigations into how people learn in informal settings like museums, science centers, zoos, aquariums, natural areas, and community organizations; (b) investigations of how people learn through media-mediated experiences (e.g., television, Internet); and (c) the contribution of free-choice learning to public understanding of science.

Informal Settings

The collective work on learning in and from museums represents the most coherent body of free-choice science learning research. These investigations have focused on why the public visits science-oriented museums, and what and how these visitors learn from visiting these institutions. In particular, adults seem to use these settings to fill the first three learning needs we identified: to fill discretionary leisure time, to build identity, as a way of improving oneself, either personally or professionally and as places to pursue hobbies and continue learning in personally meaningful ways.

The majority of this research investigates the role of exhibitions, objects, labels, and programs in educating the public. A major organizing model for research in museum settings has been John Falk and Lynn Dierking's Contextual Model of Learning (2000), which posits that learning occurs over time and is always contextual. In particular, three contexts – the personal, sociocultural, and physical – interact and influence the nature of any learning experience. Considerable work has been done in the area of personal context factors such as prior knowledge and experience (Roschelle 1995), prior interest (Falk and Adelman 2003) and motivation, and expectations (Falk et al. 2008); all of which have been shown to positively influence visitor learning.

Learning is also influenced by those with whom one visits. For example, visitors are strongly influenced by interactions they have with others in their own social group (Ellenbogen et al. 2004), with a key focus on the role of conversation (Leinhardt et al. 2002; Feinberg and Leinhardt 2002). Research also demonstrates that the quality of interactions with those outside one's social group (e.g., museum explainers, guides, or even other visitors) influences learning (Rosenthal and

Blankman-Hetrick 2002). Distinct differences in visitor interactions have been observed between all-adult groups and groups with children, particularly in terms of the behaviors of the females in the group, suggesting the importance of focusing research on adults specifically (McManus 1987). In her important dissertation study, Silverman (1990) investigated the content and function of talk by adult visitor pairs in museums observing the way adults connected and made meaning as they interacted and conversed about what they saw.

Given the cumulative nature of learning, the outcomes of museum visits have also been found to have long-lasting impact and a number of studies investigating longer-term learning suggest that short-term outcomes are frequently not predictive of the long term (Falk et al. 2004). These concerns notwithstanding, adult visitors have consistently been found to demonstrate factual and conceptual learning in the short term (Dierking et al. 2002). Finally, research has shown that although all the factors listed above do contribute to visitors' science learning, none by themselves account for a significant amount of the variance. These various factors influence science learning collectively, not individually, as predicted by the Contextual Model of Learning. And because of the personal nature of learning, challenges exist in "measuring" it. Recent research demonstrates that all visitors learn, but multiple methods of measurement are needed to document outcomes and what is learned is likely be different from individual to individual (Falk and Storksdieck 2005).

In terms of museum programming with diverse groups, two common outcomes include an increase in museum interest and/or attendance, at least in the short term, and positive changes in participants' perceptions of museums, among children *and* adults. These programs help some participants understand that museums offer fun and comfortable ways to share quality time together, and for science-interested families, an opportunity to participate in an area of interest together (Dierking et al. 2003) although there is still insufficient data to determine whether impacts from these efforts are long-lasting.

Research on the impacts of science learning from organized programs, in particular family-focused efforts, suggests that these programs are extremely effective when integrated with trusted community-based organizations that share a common goal of supporting families, youth, and communities (Luke et al. 2007). Arts programs studied by Shirley Bryce Heath (1996) showed that youth who attend after-school arts programs: (a) tend to get better grades in school; (b) are far more likely to stay in school longer, (c) are more likely to go on to higher education; and (d) are more likely to give back to their communities as adults.

Findings demonstrate that programs influence family dynamics even when parents are not involved in the program. For instance, there was evidence that interests developed within the program were carried into the home, resulting in additional shared family interests and experiences, influencing learning far broader than content knowledge. The research focused on science learning also finds that after participating in such efforts youth and families better understand processes of science and the importance of science, developing an enriched conceptual understanding and a stronger sense of science's role in their daily lives, appreciating that science is not merely "getting the right answer" but wondering, asking questions, and experimenting.

Outcomes for adults are also observed including increased parental awareness and involvement in their children's (and their own) learning, as well as a better understanding that learning is not just for children but for them also, and that learning together as a family can be enjoyable and rewarding (Adelman et al. 2000).

Although efforts often try to engage families in extended informal learning beyond the program, these impacts are much less commonly observed. Community events may encourage active participation, but findings suggest it is difficult to encourage parents to continue activities with children at home. However, participants do identify a main benefit as "expanded horizons," or "exposure to culture" (Garibay et al. 2003). There is evidence that families participating frequently do engage in some learning experiences that build on the program, including related conversations at home, family visits to other similar places, and specifically in science, conducting experiments at home, and adults assisting children with science projects. What is less clear is the long-term impact of these efforts. Preliminary findings from a US NSF-funded retrospective research project, entitled Impact of Informal Science on Girls' Interest, Engagement, and Participation in Science Communities, Hobbies and Careers, suggests that these programs do have lasting impacts on participants as they become adults, including not only choices of education and careers but also hobbies and science habits of mind (Dierking and McCreedy 2008).

Although programs designed specifically for adults, such as activities at museums and science centers, elder hostels, and other formalized experiences are becoming increasingly common, detailed investigations of these programs remain scarce. Also considerably under-investigated are the numerous hobby and science club programs although notable exceptions include the research of Flavio Azevedo (2006) and Marni Berendsen (2003) on the role of interest in influencing science learning amongst adults involved with model rocketry and amateur astronomy clubs, research on the learning of staff and volunteers at Disney's Animal Kingdom (Groff et al. 2005) and research on adults participating in citizen science activities (cf. Bonney et al. 2009). These investigations are providing some foundational understandings of how adults can and do become engaged in efforts to achieve basic science understanding through free-choice learning, but also often strive for highly developed mastery of specialized topics, and in turn serve as mentors for others, the fourth and fifth learning goals we identified.

Media-Mediated Learning

It has long been assumed that mass media, particularly news media, play an important role in informal learning, especially with regard to science and the environment. However, few studies exist which have attempted to determine the direct influence of the news media on learning about science-related issues and topics. Generalized studies include the work of the National Science Board (2008) and Falk and his colleagues (2001), which demonstrate that traditional news media represent a key source of adult information about environmental issues and science topics, even though most citizens and social scientists question the reliability of the information provided (cf. Gaziano and Gaziano 1999). Local television stands out as the main source of science and environmental information for Americans and Europeans (e.g., National Science Board 2008). The Internet is a close second for audiences seeking general science and technology information and is the primary source for those interested in specific science issues (Pew 2006).

News generation and news consumption are linked in a complex feedback loop of perceived demand and real supply (Perse 2001). Indeed, the news media can shape the agenda for public debate and political action ("agenda-setting") and the way in which the adult public perceives an issue ("framing") (Scheufele and Tewksbury 2007). Agenda-setting works largely through increased exposure; a topic becomes more visible and is, therefore, perceived to be of greater importance by the public (and other news makers, editors, and reporters). Agenda-setting can, therefore, influence public opinion and ultimately policy-making (Shanahan and McComas 1997, as cited in Nitz 1999). "Framing" refers to the way in which news media report on issues. While any issue can be reported from multiple angles, the preferred reporting narrative determines how the public understands the nature of an issue (rather than the importance of it). The preferred narrative is a function of the newsroom characteristics cited earlier. The resulting "frames" focus on certain aspects and angles of a topic while ignoring or minimizing others (Nisbet and Mooney 2007). Science and technology (and environmental issues) are often discussed in the mass media with frames that focus on conflict and controversy (e.g., Nisbet and Lewenstein 2002). Particular media content or frames, like public opinion polls, can not only grab the public's attention, but this attention can ultimately impact learning, attitudes, and behavior (Moy et al. 2004).

These investigations reinforce the generally held assumption that broadcast media can and do influence learning, but impacts are typically modest and often very idiosyncratic. The true power and potential of broadcast media may be best understood in culturally popular contexts. The recent popularity of medical emergency and crime scene investigation on television in the USA has resulted in significantly elevated public understanding of these two topics, and significantly increased enrollments in associated graduate programs (including individuals from historically underrepresented groups in science such as women and minorities (Whittle 2003).

As mentioned above, the Internet has revolutionized where, how, when, why, and with whom the public accesses information. However, like other types of educational research, the majority of virtual learning studies have focused on classroom-based practices for children, not free-choice learning among adults (Haley Goldman and Dierking 2005). This research gap exists for several reasons, including most significantly the methodological obstacles in conducting research on a "non-captive" virtual audience. Existing research focuses disproportionately on usability issues, such as ease of navigation. This focus is important and has significantly contributed to improvements in the quality of online learning resources, but unfortunately it also obscures more critical issues such as how, why, and to what end people use the Internet to learn (cf. Dede 2005). For example, the Internet has become a dominant way for adults to get answers to health-related issues and questions about themselves and significant others (Flynn et al. 2006). Given current trends that indicate the Internet and other digital media are increasingly supplanting television as the primary way youth spend their free time (Yelland and Lloyd 2001), it is fair to assume that the impact of media on science learning will become increasingly important to understand as today's youth move into adulthood.

Public Understanding of Science

At the heart of all science education efforts is the goal of promoting public science literacy – a generalized body of scientific understanding and capabilities, historically described as a combination of knowledge and a set of scientific practices and habits of mind (Brown et al. 2005). Science literacy is considered an essential component of a democratic society, supporting a modern technology-based economy and promoting cultural values of society. In particular, civic science literacy, the ability to keep informed about current events in science and to actively participate in a scientifically and technologically advanced society, has been deemed an essential goal of society (Schibeci 1990).

Despite evidence that the majority of the public finds science interesting enough to invest considerable leisure time pursuing science-related learning (National Science Board 2008), most studies attempting to measure public general knowledge and understanding of science and technology conclude that the public is largely scientifically disinterested and illiterate (cf. Bauer et al. 2007). A major conclusion of this research is that the best predictor of public science literacy is college-level courses in science (Miller 2001), although it is acknowledged that informal science education experiences also contribute. Results of this research have been widely used to judge the level of science literacy of entire nations; however, these results need to be interpreted with caution because they primarily assess what adults do not know ("deficit model"), rather than what they actually do know (Irwin and Wynne 1996).

The main thrust of recent criticism of current science literacy assessments has been that the "deficit" model of assessment measures the layperson's knowledge based upon what an expert scientist would deem appropriate across a wide array of topics. These assessments typically use school-like tools that assume an individual's functional literacy would be directly, even linearly, correlated with the extent of his or her factual understanding of a set of generalized scientific information and principles. By contrast, others have argued for a more situated approach, which assumes that attitudes toward and knowledge and understandings of science are more likely to be shaped by an individual's direct and personal experiences, needs, expectations, and culture (Falk et al. 2007).

For most adults, interest in science is linked with decision-making or action, that is, science for specific social purposes (Jenkins 1999), including personal matters (e.g., health or child care), employment (e.g., safety at work, risk assessment), leisure (e.g., choosing the best fishing rod, fabric, mountain bike), or individual or organized protest (e.g., at a proposal hearing to build a nearby nuclear plant). An adult who wishes, individually or as part of a group, to engage seriously in a debate about an issue which has a scientific dimension sooner or later has to learn some of the relevant science. However, matters are rarely as straightforward as simply seeking the relevant scientific information. The information may not be in a form in which it can be used (Layton et al. 1993), it might be unavailable (Wynne 1996) or, as in the case of some situations such as pharmaceuticals, not in the public domain. In addition, even when scientific data are available, there may be argument about the methods by which the data were obtained, about the extent to which generalizations may be sustained, or about the significance to be attached to the findings (Jenkins 1999). When it is available, the scientific information may also be unnecessarily sophisticated and overelaborate for the purposes at hand. For example, heating engineers tend to think of heat as something which "flows" because it is "convenient," rather than the "more correct" kinetic theory of matter.

In much the same way, lay adults choose a level of explanation which meets their needs. In a classic study, workers in a computer company chained to their benches by an earthed metal bracelet in order to prevent damage by static electricity to sensitive electrical components, conceptualized electricity as a fluid which either piled up or was discharged, where it was dispersed or "lost" (Caillot and Nguyen-Xuan 1995). This less than scientific model of electricity enabled the workers to function safely and to make sensible decisions when confronted with problems. These scientifically incorrect understandings or misconceptions were also well tested in the context of experience and action and, in those contexts, had served the workers well. All citizens construct a body of practical knowledge, tested and validated against their individual and collective experience. In deciding how and when to act in practical matters that have a scientific dimension, scientific knowledge is considered alongside other experiential and personal knowledge bases (it is important to acknowledge that while such practical knowledge may be adequate in many contexts, such knowledge can be misleading or even dangerous).

What is important to note though is that this latter approach to assessing science literacy begins from the premise that science learning is a natural and common outcome of living within a science-rich world, situated within activities of everyday life (cf. Roth and Calabrese Barton 2004) and posits that science learning, like all learning, is driven by each individual's need to know. From this perspective, each individual in a community is likely to have a different science knowledge repertoire; a level of science understanding determined by his or her specific needs, abilities, and socio-historical context. Public understanding of science is not some generalized body of knowledge and skills that every citizen should have by a certain age, but rather a series of specific sets of only moderately overlapping knowledge and abilities that individuals construct over their lifetime. From this perspective, individuals possessing comparable science understandings would best be predicted by convergences in life experiences, professions, hobbies, and interests rather than convergences in schooling.

This view of science literacy suggests that accurately assessing public "working" science knowledge requires one of two approaches: (a) more qualitative methods that allow individuals themselves to self-select and direct data collection; or (b) more quantitative methods that restrict assessment to a subset of STEM topics appropriate to the situated realities of a specific population. The former approach was used by Wolfgang Wagner (2007) and a variation on the second approach was used by Falk, Martin Storksdieck, and Dierking (2007). Both studies concluded that informal experiences such as reading unrelated to schooling, museum-going, interactions with peers and workmates, and Internet use were the predominant mechanism by which the public sought and acquired science understanding. One of the interesting, counterintuitive findings from the research on Canadians' free-choice learning (Livingstone 1999) was that among those surveyed, the less schooled appeared to be at least as competent as the more highly schooled on significant dimensions of science understanding. In another study, adult amateur astronomers were found to be highly knowledgeable about astronomy, and years of club membership and engagement in education and public outreach activities were far better predictors of their astronomy knowledge than formal training in science and astronomy (Berendsen 2003). These findings were also reinforced in a recent study focused on public understanding of evolution in which many knowledgeable adults' sources of information about evolution were nonschool in origin including television programs, books, magazines, and museums (MacFadden et al. 2007). We know that the public engages in leisure science learning, and we understand some of the rudimentary ways in which adult learning differs from that of children (Sachatello-Sawyer et al. 2002). However, what remains relatively poorly understood, is the extent of the adult public's free-choice science learning and the cumulative effects of free-choice learning experiences on their self-defined knowledge of science, what we call working knowledge of science.

Future Directions

As we strive to understand and support efforts to foster increased public science interest, knowledge, and understanding we need to be aware of the vast number of ways, ages, and places in which a person learns science across his or her lifetime including as an adult. Free-choice learning institutions such as museums, the Internet, and broadcast media to name but a few, are assuming an evermore prominent role in lifelong science learning. All of these opportunities represent important, in fact essential ways that we learn and most importantly, *contextualize* our science knowledge and understanding throughout our lifetimes. If we, as science learning researchers and educators in the twenty-first century, want to move beyond the rhetoric of supporting lifelong science learning, it is critical that we recognize, understand, and learn how to facilitate free-choice learning as a powerful vehicle for lifelong science learning. Free-choice learning is not just a nicety, nor is it merely a way to support school-based science learning. Free-choice learning is an essential component of *lifelong* science learning in its own right. To not understand and embrace this form of learning as an essential component of an *adult* citizen's science education is to seriously impede our ability to enhance public science learning. In order to do so effectively, two key aspects of this enterprise must be considered: (a) awareness and recognition of the true scope and scale of the science learning infrastructure of a community; and (b) a vision of future science education research that reframes questions of science learning within the context of a person's entire lifetime.

The Science and Technology Education Infrastructure

Over a decade ago, educational evaluators Mark St John and Deborah Perry (1994) proposed that the educational field rethink how they conceptualize the entire learning enterprise, suggesting that the school and free-choice learning sectors (and we would add the workplace) be considered components of a single, larger educational infrastructure. They used the term infrastructure to describe the system of supports, conditions, and capacities that permit the smooth functioning of daily life. The educational infrastructure in a community supports and facilitates the learning that takes place there. Ideally each community has a richly integrated, broadly supported educational infrastructure, a system of support that enables millions of unique individuals to meet their widely varying science learning needs anytime of the day, at any point in their life. This basic educational infrastructure already exists, composed of schools and universities, the Internet, print and broadcast media, libraries, museums, zoos, aquariums, community-based organizations, the workplace, hobby groups, social networks and friends and family, and many facets of which already function as an integrated community of practice (Falk et al. 2008). However, there is still considerable room for improving the ways all of these educational entities work together to support and sustain science learning across the life span, particularly for adults.

The science learning infrastructure serves as a web of influence that shapes people's understandings, attitudes, aesthetic beliefs, and values. And although schools and universities are important parts of this infrastructure, so are museums and science-technology centers, broadcast media, community-based organizations, libraries, and increasingly a whole host of "bottom-up" organizations such as hobby groups and web-based social networks. The implications of this notion of infrastructure are that we look for science and technology teaching and learning in novel places. For example, the Astronomical Society of the Pacific, based in San Francisco, CA, with funding from the US NSF over the last 15 years, has explored and experimented with ways to tap into the vast resource of adult amateur astronomers (Dierking and Richter 1995). They have involved these astronomers in supporting elementary and middle school teaching in classrooms through Project ASTRO, created Family ASTRO, an effort to provide fun and engaging astronomy experiences to families through the network of museums, science-technology organizations, and community-based organizations such as scouts, and now are providing more focused astronomy training to free-choice learning educators working in small science centers, museums, and planetariums. This effort represents a creative way of brokering connections within the science and technology learning infrastructure since there is growing evidence to demonstrate that the more the three educational sectors of school, work, and free-choice learning overlap in people's lives, the more successful they are at becoming lifelong science learners (Knapp 1997).

If the goal is to embrace a broader notion of learning, it is critical to identify what we might be looking for, where to start looking, and how to look. Here are some brief and tentative ideas for such a strategy. Given how limited our current understanding of lifelong science learning is, coupled with the rapidly changing social, cultural, and economic landscape of the twenty-first century, we offer these ideas with great humility.

We envision two broad lines of research. The first is a top-down view that attempts to deeply understand the structure and functioning of existing, as well as potential interrelationships between actors and agents in the learning landscape with a focus on adults. The second is a bottom-up view that begins with the adult learner and attempts to deeply understand the ecology of learning for life from a learner-centered perspective. Both of these lines of inquiry will require teams from multiple disciplines and will be more robust if they involve both researchers and practitioners and occur across extended time frames (*at least* 5–10 years).

Future Research Directions: The Learning Landscape

Although it is not a large conceptual stretch to envision a complex community infrastructure of learning resources that supports and facilitates the science learning that takes place there, it is quite another thing to understand how it actually functions on the ground for learners. We know that this basic science learning infrastructure already exists in virtually every community, including traditional constituents such as schools and universities, print and broadcast media, libraries, museums, zoos, aquariums, community-based organizations, and the workplace. We also know that increasingly these institutional constituents are being supplanted by noninstitutional, more fluid entities such as hobby groups and social networks, both virtual and physical. Yet currently, we know precious little about how this learning infrastructure functions and how the various pieces intersect and interact. Gaining better insights into the structure and workings of this learning infrastructure will need to be an important element of any future research endeavor. As the historical distinctions between formal and informal education are increasingly less useful, we need a better understanding about the basic nodes of the learning infrastructure, how they interconnect, and how much variability exists in the nature of these infrastructures from community to community. In short, we need to investigate the structure and functioning of the learning landscape.

Historically, investigations of science learning have been quite bounded. Most studies have investigated a single topic area, a specific age cohort, within classrooms, over the time frame of a unit or at most a school year. Even investigations of free-choice learning have typically been equally bounded (visitors to a specific museum, often a single exhibition, framed by the duration of a single visit). Everything we have learned about the nature of learning in general and science learning in particular, suggests that it is rarely instantaneous and does not occur in one place at one time; instead it is strongly socioculturally framed and cumulative. We need to expand the scope and scale of our investigations to better encompass the realities of lifelong science learning. We need to give greater emphasis to the adult years of science learning since this is not only where most people spend the majority of their lives it is also the time when most science learning occurs. In particular, the aging of America represents another research opportunity. We know that learning is important to staying young and fit but there is little research that has specifically focused on the learning of seniors and elders (Doering and Bickford 1994). Over the next few decades, older adults will become an ever-larger percentage of the population (U.S. Department of Commerce 1996), but they will not be like past generations of older adults (Krugman 1996). Aging Baby Boomers will be better educated, healthier, more affluent, and more adventuresome than their predecessors (Foot and Stoffman 1996). Collectively, this population will represent an important, and as of yet, poorly understood group of adult science and technology learners. Implementing these changes will require different methods, different questions, and different types of financial investments. It also will require new partnerships between organizations and individuals – partnerships that better reflect the actual structure and functioning of where and how the public learns science.

Future Research Directions: An Ecology of Learning for Life

Like the prevailing economic models of that time, throughout the twentieth century the focus of science learning investigations was top-down with an emphasis on instruction and curriculum. The organizing framework was that institutions could provide all that was necessary for an informed, science-literate citizenry. Nations and states set up school systems to cater to the learning needs defined by the society and specific institutions in the society, such as corporations and government entities; schooling was designed to satisfy these constituencies and insure that learners met specific competencies. Learners were expected to appreciate having these opportunities and to meet curricular demands in order to further their career development. While there is increasingly greater openness toward learner participation in structuring the learning experience and the environment in which it takes place, the learner is still basically expected to accept the package for what it is. The learner is the consumer of a highly "engineered," readymade or, at best, partly customizable product.

This is not the reality of the twenty-first century. Learning, like economic innovation, is increasingly becoming bottom-up, controlled by the individual, and highly focused on meeting personal needs and interests, particularly for adults. This shift has huge implications for not only how learning occurs, but how research on learning should be conducted. In the new world order, the learner's role is quite different. Although the reasons for learning may sometimes still be associated with the pursuit of formal learning objectives or career goals, as research cited in the above documents, the majority of individual-generated science learning will be aimed at meeting identity-related needs unassociated with degrees and employment – science learning related to hobbies, personal curiosities, or individual needs such as environmental preservation in the neighborhood, or responding to health issues. Not too long ago only the few had access to society's collected knowledge; knowledge was housed in carefully guarded and preserved libraries and universities behind cloistered walls. Individuals were initiated into the world of knowledge by the "knowledge priests," but only if they followed the rules of the order. Today and in the future, anyone can have access to the world's knowledge, anytime of day, wherever they may live, with just a few keystrokes. Adults now are faced with a panoply of science education offerings, at home through online programs, games, or websites or via broadcast media, by venturing outside and visiting science museums, natural parks, in summer camps, elder hostel events, while vacationing or after work at a science pub night. All of these offerings now compete in the leisure marketplace; all are attempting to put the learner's needs and interests first. This changed learning landscape makes historical top-down models of science learning research as obsolete as the institutions sponsoring them.

Arguably, also obsolete are traditionally narrow notions of what constitutes learning. Most science education research is still predicated on conceptualizations of learning that make sense within academic contexts – mastery of facts and concepts in order to orally or in writing describe and defend an idea or proposition. Within the world of free-choice learning, learning is primarily for personal fulfillment and often strongly motivated by the needs of identity formation and reinforcement. In this context, learning tends to take the form of confirmation of existing understandings, attitudes, and skills in order to allow the individual to be able to say: "Okay, I now know that I know/believe that." The goal is not "mastery" in the traditional sense, but rather to provide the individual with a feeling of personal competence. We currently are not well equipped to measure and assess this kind of learning.

We need a more learner-centered approach to science education research that places issues of learner motivation and identity at the center of inquiry. One approach to this perspective has been pioneered by Jan Visser (1999) who has argued that learning entities at different levels of organizational complexity – ranging from the individual to the social – behave like Complex Adaptive Systems (CAS). He argues that it is crucially important to recognize the ecological wholeness of the learning environment, where learners are simultaneous producers and consumers; resources and users of resources.

We would suggest that future investigations of science learning need to situate the learner at the center rather than the periphery of the learning process; as an active co-constructor, not merely a passive recipient. In order to meaningfully understand what learning is but even more importantly, why it happens, studies also should frame learning within the larger ecological context of an individual's life and the learning landscape in which he or she participates. We believe these findings and new directions support the necessity of further exploration of science learning across the life span. Taken together, increasing an emphasis on free-choice learning and its connection to other aspects of the learning landscape, holds the promise for more effectively understanding and achieving measurable, long-lasting impacts on the adult public's science understanding and interest, science learning for personal fulfillment, as well as for an informed citizenry.

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Chapter 71
Science, the Environment and Education Beyond the Classroom

Justin Dillon

Introduction

Much of the research in science education is rather inward looking. We focus on students' ideas and attitudes, science teacher knowledge and pedagogy, the nature of science, inquiry-based science education, and scientific literacy. However, because science inside and outside school sits in a much broader context, I take a more outward-looking approach to science education in this chapter. The focus of this chapter is on the relationship between science education and environmental education – a relationship that is contested and not particularly well researched although it is critical if science education is going to respond to the environmental challenges facing the planet and all who live on it.

I begin by making my own position clear so that you know to read what follows with an eye on where my thinking lies. In the introduction to a special issue of the *International Journal of Science Education* on Perspectives on Environmental Education-related Research in Science Education published in 2002, William Scott and I wrote that 'environmental education offers a conceptual richness that challenges current thinking in science education because of its multi-disciplinary origins and traditions' (Dillon and Scott 2002, p. 1112). Writing in the same special issue, Annette Gough, an Australian environmental education (EE) researcher, argued for a degree of mutualism between the two fields: 'Science education needs EE to reassert itself in the curriculum by making science seem appropriate to a wider range of students and making it more culturally and socially relevant' (Gough 2002, p. 1210). Specifically, Gough argued:

> EE needs science education to underpin the achievement of its objectives and to provide it with a legitimate space in the curriculum to meet its goals because they are very unlikely to be achieved from the margins. (p. 1210)

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As Gough intimates, EE, a relative newcomer to the curriculum, has been rather marginalised for some time and is rarely afforded a place at the educational high table. Having said that, there are examples in countries such as South Korea, Australia and Canada of EE being taken very seriously by curriculum planners and by policy makers. Space precludes a detailed discussion of why EE has had to struggle to survive in many countries, but the barriers have included pressures from other more traditional subjects and, in some cases, a suspicion of the political leanings of EE researchers (e.g. Hungerford 2010). It is also necessary to point out that environmental education is a contested term and the advent of terms such as 'education for sustainability' and 'education for sustainable development' has confused the field even further. Having said that, the environment has never been as significant to discussions about what is taught in schools as it is now.

However, what is taught in schools, particularly in the name of science education, has many critics (Rocard et al. 2007). The evidence from surveys such as the Relevance of Science Education (ROSE) suggests that the content of the science curriculum, coupled with the way that it is taught and assessed, put many students off science for life (Osborne and Dillon 2008). Focusing on issues of health and the environment might motivate more students to appreciate the value of science and to consider studying it for longer either at school or elsewhere. Scott and I have argued:

> Environmental education provides an opportunity to bring in modern and challenging social and scientific issues into the classroom that is currently hindered by the packed and conservative science curricula of many countries around the world. (Dillon and Scott 2002, p. 1112)

So, at a time when student interest in school science is a cause of concern for policy makers and science educators, introducing environmental issues into the curriculum might be seen as a win–win option: students will be interested in science more; and they will learn more about environmental issues and contribute to a more sustainable future. However, research points to a number of barriers to such an approach. Firstly, Chris Gayford (2002) argues that including controversial issues such as the impact of climate change in school science might not relate well to the existing schemes of work and curriculum organisation. Gayford also notes that understanding issues such as climate change requires a range of knowledge of many subjects that science teachers might not possess. The implication here is that either teachers will need to develop their own knowledge of environmental issues or that more cross-curricular approaches to these topics need to be found.

Inclusion of controversial issues, such as global climate change, within the school science curriculum presents several challenges to teachers: first, the controversial nature of the topic; second, it does not relate well to the normal sequencing and division of topics within most science courses; and, third, there are important non-scientific aspects to possible solutions to the problem. Marcus Grace and Mary Ratcliffe (2002) identify another related problem as being that most environmental issues affecting society are underpinned by value judgements and the border between 'scientific statements' and 'value statements' can be hard to see. Some science teachers are neither well prepared to teach about controversial issues nor necessarily happy to do so (Oulton et al. 2004). Another challenge identified by Daan van

Weelie and Arjen Wals (2002) is that teachers' understanding of the language of sustainability and biodiversity might not be adequate for teaching complex environmental topics.

The call to make science education more culturally and socially relevant is not new (e.g. Roth and Barton 2004). The challenge facing science education was eloquently summarised by members of the 2007 Linné Scientific Literacy Symposium in their Statement of Concern:

> Science education, perhaps because of the sheer depth and volume of the knowledge base of modern science, has isolated that knowledge from its historical origins and hence students are not made aware of the dynamic and evolving character of scientific knowledge, or of science's current frontiers [...] Nor is there any real sense of any meaningful exploration of issues that relate ethical and personal accountability to modern scientific activity. Indeed, the existence of human enterprise that makes science possible is almost ignored in science education. Curricula and assessment need to support teachers' being able to share the excitement of the human dramas that lie behind the topics in school science with their students. (Linder et al. 2007, p. 7)

The key issue here is that the reform needed in science education, if it is to become more culturally, socially and environmentally relevant, involves parallel changes in curriculum, pedagogy and assessment (Barron et al. 1998). Ideally, such changes need to be underpinned by a secure research base.

Education and the Environment

The central role that the environment occupies in the collective consciousness is evident in many aspects of everyday life. Just one example of this phenomenon can be gleaned from the Global Plan for Recovery and Reform, the final communiqué issued at the end of the G20 London Summit in April 2009. Paragraph 4 of the plan lays out the participants' commitment to 'repair the financial system to restore lending' and also 'to build an inclusive, green, and sustainable recovery' (G20 2009). Paragraph 28 spells out the politicians' commitment 'to address the threat of irreversible climate change'. This interlinking, at the policy level, of the financial and the environmental dimensions of our lives is relatively new and offers challenges and opportunities to science and environmental educators. Ironically, climate change has presented a sad moment of opportunity to look again at what science education can offer environmental education and vice versa. It is no exaggeration to say that climate change is perceived as one of the greatest threats to the lives and livelihoods of current and future societies.

Despite the potential consequences of a failure to respond to that threat, science and environmental educators around the world have struggled in the search for reliable strategies that will lead to a sustainable future for new generations. The struggle, though, is being taken up by an increasing number of researchers using a wide range of methods and methodologies. While some scholars focus on links between an individual's knowledge, attitudes and behaviors, others examine the value of indigenous people's knowledge and practices. Whereas some researchers evaluate the effectiveness of particular experiences, others critique the whole nature of education for sustainability (e.g. Jickling 2001). It is a field that is increasingly diverse conceptually, philosophically and methodologically.

Researching Education, Science and the Environment

Early conceptualisations of environmental educators tended to reflect a view that science had a fundamental role within it. Such a position is characterised by this definition from 1969:

> Environmental education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its problems, aware of how to help solve those problems, and motivated to work toward their solution. (Stapp et al. 1979, p. 31)

Many of the early researchers in environmental education had backgrounds in one or more of the sciences. In more recent years, the field has broadened significantly but the first home of environmental education research tended to be science education journals, although the warmth of the welcome varied considerably. Signs of the growing maturity of the relationship between the science education and the environmental education research communities can be seen in the recent establishment of an EE strand within the US National Association for Research in Science Teaching.

The breadth of EE research, methodologically and geographically, can be judged by the growing number of international peer-reviewed journals in the area. For many years, the *Journal of Environmental Education (JEE)*, originally published by Heldref, was regarded by many as *the* place to publish. However, frustration in the field with the perceived narrow range of research published in *JEE* contributed to the establishment of a range of new outlets. Nowadays, scholars in the field have a choice of where to publish their findings. Each journal has its own character and philosophy and the leading journals include *Environmental Education Research*, the *Canadian Journal of Environmental Education*, the *Australian Journal of Environmental Education* and the *Southern African Journal of Environmental Education*. The crossover between science and environmental education has been further established by the publication of special editions focused on environmental education by established science education journals such as the *International Journal of Science Education* (1993: 15(5) & 2002: 24(11)) and the *Canadian Journal of Science, Mathematics and Technology Education* (2010: 10(1)). Publishing opportunities for educational research on science and environment issues have never been so plentiful.

Science Education Beyond the Classroom

One interesting dimension of the science and environmental education crossover or interrelationship is the increasing focus on learning outside the classroom. Recent years have seen a growth in research into learning in informal contexts such as museums, science centres and botanic gardens; some of this research is covered elsewhere in this volume. In this section, the focus is on relationships between aspects of science education and environmental education in the context of learning beyond the classroom because it is this dislocation of traditional science education that raises a series of interesting issues and challenges.

The relevance of much of this research to science teachers is becoming increasingly clear. In England, for example, the government supported the publication of the *Learning Outside the Classroom Manifesto* (DfES 2006) which encourages teachers to consider the use of museums, science centres, theatres, farms, etc. when they plan lessons. The US National Education Standards state that museums and science centres 'can contribute greatly to the understanding of science and encourage students to further their interests outside of school' (NRC 1996, p. 451). According to the *Washington Post*, 'as more children struggle with obesity and awareness grows about global warming, outdoor learning is becoming a popular education concept' (2009, p. B02) noting that a 'No Child Left Inside' movement is gaining momentum. Science teachers are increasingly seen as key contributors to health, environmental, social and citizenship issues (e.g. Ratcliffe and Grace 2003).

Launching the *Learning Outside the Classroom Manifesto*, in November 2006, Alan Johnson, the UK's Education and Skills Secretary said:

> Learning outside the classroom should be at the heart of every school's curriculum and ethos. Children can gain valuable learning experiences – from going on cultural visits overseas, to teachers simply using their school grounds imaginatively. Educational visits and out-of-school teaching can bring learning to life by deepening young people's understanding of the environment, history and culture, and improving their personal development. (UK Government 2006)

The focus of the next section is research in science and environmental education outside the classroom.

Research into Science and Environmental Education Outside the Classroom

Reviews of Research into the Impact of Science Learning Beyond the Classroom

A major review of the impact of education outside the classroom is *Every Experience Matters* by Karen Malone (2008) on the role of learning outside the classroom for children's whole development from birth to 18 years. Malone's report was commissioned by a charitable trust – Farming and Countryside Education – in support of the UK Department of Children, School and Families *Learning Outside the Classroom* Manifesto mentioned above. The author concludes that 'the review provides evidence that by experiencing the world beyond the classroom children' (p. 5):

- Achieve higher results in the knowledge and skill acquisition;
- Increase their physical health and motor skills;
- Socialise and interact in new and different ways with their peers and adults;
- Show improved attention, enhanced self-concept, self-esteem and mental health;
- Change their environmental behaviours for the positive, as do their values and attitudes and their resilience to be able to respond to changing conditions in their environment. (p. 5)

Perhaps, in the light of the discussion above about the need for behavioural change, Malone's conclusion that learning outside the classroom can change participants' environmental behaviours for the positive is the most striking. Much of the early research in environmental education focused on examining the links between knowledge, attitudes and behaviours. Indeed, that tradition still continues. In a special issue of the *Journal of Environmental Education* celebrating its 40th anniversary, Philip Short claims: 'Ultimately, EE must aim for action-informed, thoughtful, scientifically grounded, democratic action' (2010, p. 8). This position might not have been out of place in the first edition of the journal. However, this stance has been the subject of substantial criticism from those who see it as rather narrow and, ultimately, positivist and behaviourist in nature. Ian Robottom has queried the 'appropriateness of applied science approaches to evaluation in environmental education' in arguing for 'a deliberative choice of research paradigm in environmental education' (1989, p. 435).

Malone's review drew on five types of research (quantitative, qualitative, mixed-method, action/participatory research and literature reviews). Her team reviewed more than 100 studies, to which approximately half were referred in the final report. Malone contends that a number of significant research studies

> …support a general hypothesis that learning outside the classroom has a significant impact on children's learning and is supportive of healthy child development in the cognitive domain (children's learning), physical domain (children's physical experiences), social (children's social interaction), emotional (children's emotional well-being) and personal domains (children's responses). (p. 13)

Malone's review deliberately builds on an earlier report, *A Review of Research on Outdoor Learning*, by Mark Rickinson, Justin Dillon, Kelly Teamey, Marian Morris, Mee Young Choi, Dawn Sanders and Pauline Benefield (2004), carried out on behalf of a range of funders including non-governmental and governmental agencies. The Rickinson et al. (2004) review critically examined 150 pieces of research on outdoor learning published in English between 1993 and 2003. The literature encompassed three main types of outdoor learning with elementary school pupils, high school students and undergraduate learners: fieldwork and outdoor visits; outdoor adventure education; and school grounds/community projects. The authors reported that they found 'substantial evidence to indicate that fieldwork, properly conceived, adequately planned, well taught and effectively followed up, offers learners opportunities to develop their knowledge and skills in ways that add value to their everyday experiences in the classroom' (p. 5). The majority of the fieldwork studies involved either science or geography education (e.g. Orion and Hofstein 1994).

The review noted that 'fieldwork can have a positive impact on long-term memory due to the memorable nature of the fieldwork setting' (p. 5) and added:

> Effective fieldwork, and residential experience in particular, can lead to individual growth and improvements in social skills. More importantly, there can be reinforcement between the affective and the cognitive, with each influencing the other and providing a bridge to higher order learning. (p. 5)

This key finding provides a major justification for shifting the pedagogy of science beyond the classroom and, indeed, beyond the school boundaries. If traditional science education in developing countries leads to increased subject knowledge at the expense of interest in the subject, then learning outside the classroom might allow teachers to

> …focus on helping learners deal with the sheer complexity and splendour of the environment as well as looking to use the local environment as a vehicle for developing understanding of the more mundane aspects of the science curriculum. (Dillon and Scott 2002, p. 1112)

Rickinson et al. noted, however, that despite substantial evidence of the efficacy of fieldwork (in many curriculum subjects) 'there is evidence that the amount of fieldwork that takes place in the UK and in some other parts of the world is severely restricted, particularly in science' (p. 5). Reasons as to why this might be the case have been posited for some time and include fear of litigation, lack of teacher training, and cost; however, many teachers do take their students on trips to the local environment or beyond. More research is needed into why the barriers for some teachers are not perceived as such by others. In terms of other gaps in the research base, Rickinson et al. noted that '[t]he number of studies that address the experience of particular groups (e.g. girls) or students with specific needs is negligible' (p. 5).

Empirical Studies of the Impact of Science Learning in the Environment

Not surprisingly, research suggests that students remember fieldwork and outdoor visits for many years. Among the many researchers reporting such findings, Lynne Dierking and John Falk (1997) found that 96% of a group of children and adults ($n = 128$) were able to recall field trips taken during their early years at school. The question, however, is whether it is enough that people remember such visits. An argument can be made that one of the purposes of schooling is to provide memorable events on the basis that students might draw from a wider set of experiences during their future education.

Evidence for the relative efficacy of fieldwork comes from a study of secondary students from 11 Californian schools that used an environmentally focused curriculum. The students scored higher in 72% of the academic assessments (reading, science, mathematics, attendance rates and grade point averages) than students from traditional schools (SEER 2000). Although few studies have used this approach to compare groups of schools with different curricula and pedagogies, it might well carry more weight with policy makers who want to know 'what works'.

Dennis Eaton (2000) set out 'to determine whether an outdoor education experience would have a more positive impact on the cognitive achievement and environmental attitudes of junior-level students than in a traditional classroom setting' (p. ii). Eaton's participants were six classes who attended a half-day program in beaver ecology at an Outdoor and Environmental Education Center. Another six classes were taught similar content in traditional classrooms (control group). Eaton found that the outdoor centre 'made a greater contribution to cognitive learning compared to the classroom programme' (p. iii). However, Eaton noted that neither context seemed to have an impact on environmental attitudes. The issue to be explored here is the extent to which the program focused on knowledge and to what extent it focused on deliberately trying to change attitudes and/or behaviour.

Eaton's results contradict several other findings of attitudinal changes resulting from experiences outside the classroom. Stuart Nundy's (1998, 1999a, b) study of the role and effectiveness of residential fieldwork on UK upper primary [elementary] school students, for example, revealed an interaction between cognitive and affective impacts:

> Residential fieldwork is capable not only of generating positive cognitive and affective learning amongst students, but this may be enhanced significantly compared to that achievable within a classroom environment. (Nundy 1999a, p. 190)

In Australia, Cecily Maller (2005) identified a number of aims for engaging children in hands-on contact with nature noting several reasons for its increasing popularity:

> Many schools, both in Australia and internationally, are including hands-on contact with nature in their curricula, usually to meet sustainability education, environmental education or science learning objectives. However, other reasons cited for the recent growth in these types of activities include beautification of school grounds, habitat restoration, and fostering qualities of stewardship and nurturing in children. (p. 16)

Maller's doctoral study involved a postal survey of 500 urban Melbourne primary schools, a more in-depth study of 12 schools and interviews with seven 'key industry informants' including an education officer of an environmental education organisation, a landscape architect and the manager of a community garden. Reporting only on the interviews, Maller found that 'hands-on contact with nature in primary school, regardless of the type, is an important means of connecting children with nature and can play a significant role in cultivating positive mental health and well-being' (2005 p. 16). Maller concluded:

> The take-home message from this research is that hands-on contact with nature experienced via sustainability education is not only essential for protecting the environment, but it also appears to be a means of cultivating community and enhancing the mental health and well-being of children and adults alike. (pp. 21–22)

Maller found that her respondents identified what she describes as structured and unstructured hands-on activities and that, while structured activities 'result in greater benefits to children's mental health and wellbeing, unstructured activities were thought to be important for connecting children with nature and fostering an interest in the environment that may emerge later in adult life' (p. 21).

Maller also claims that structured activities, 'such as those commonly occurring in sustainability education', were seen as being 'powerful catalysts for creating a stronger sense of community – both within and beyond school boundaries' (p. 21). Maller's claims are rather bold and more longitudinal research is needed to see if they can be substantiated. One of the issues is that proponents of any educational initiative will tend to perceive benefits when they might be neither directly attributable to the intervention nor independently measurable.

Research into one-off experiences or short-term programs are more common than studies of long-term interventions. Research into a long-term project is described by Tracy Coskie, Michelle Hornoff and Heidi Trudel (2007). During a 5-week study, students aged 8–10 years learned how to write a field guide to identify plants in a small area of woodland near to the school. Coskie et al. found that students 'came to understand and care for the natural world in their immediate environment. They also developed important science, reading, and writing skills through purposeful work' (p. 26). Such studies lie at one end of the spectrum that has a focus on science knowledge and skills at one end (such as this one) and a focus on health, well-being and sustainability issues at the other.

In a study that moves from the science knowledge end of the spectrum to a focus on conservation, Christoph Randler, Angelika Ilg and Janina Kern (2005) report on two classes of students aged 9–11 years who learned about amphibians. Around half of the students also took part in conservation work outdoors which involved them in encountering living amphibians. The authors found that the students who had taken part in the conservation action 'performed significantly better on achievement tests' and that pupils 'expressed high interest and well-being and low anger, anxiety, and boredom' (p. 43). The authors also found that feelings of 'boredom and anxiety correlated negatively with residualized achievement scores' (p. 43). Randler et al. concluded that learning about biodiversity should '(a) focus on a small number of species, (b) start in primary schools, (c) take place outdoors, and (d) be linked with classroom teaching' (p. 43). Increasingly, studies of science learning beyond the classroom are focusing on the importance of integrating activities inside and outside the classroom (e.g. DeWitt and Hohenstein 2010).

Plants, as well as animals, have been the focus of teaching about and in the environment. *Spring Bulbs for Schools*, a museum outreach program established in Wales in 2006, was investigated by Danielle Cowell and Richard Watkins (2007). The study involved 160 monitoring sites being set up across the Principality. Few details are given about the age of the pupils although a Year 6 class (ages 9–10 years) is mentioned as taking part. The authors, one of whom was a project officer and the other a schoolteacher, evaluated the project and found:

> Working with crocuses and daffodils made [participants] aware of the importance of bulbs in the life cycle of some plants. On a more general level, they become aware of the world around them and the idea that human activity can have noticeable effects, even on a local scale in the school garden. (p. 27)

The authors added that, at a more general level, 'the project enabled them to undertake pattern-seeking and observational activities – aspects of scientific enquiry that are often underdeveloped throughout the science curriculum' (p. 28). The increased focus on inquiry-based science education in Europe and elsewhere (Rocard et al. 2007) might provide opportunities for the further promotion of science beyond the classroom.

The impact of visits to the Eden Project, a visitor attraction and educational centre in Cornwall, UK, has been reported by Rob Bowker (2004, 2007). Bowker examined pre- and post-visit drawings of tropical rainforests made by 9–11-year-old children. Before the visit to the Humid Tropics Biome, the children's pre-visit drawings 'mainly showed tree and plant outlines familiar to an English countryside' (2007, p. 75). Bowker reported:

> Rainforest animals were to the fore in the pictures and there was a general lack of scale, depth and perspective in the drawings. In the post-visit drawings, the animals had mainly disappeared. There was often remarkable accuracy in the shape and detail of the tropical rainforest trees and plants now drawn. The post-visit drawings also demonstrated far greater depth, scale and perspective than the pre-visit drawings. (2007, p. 75)

In an earlier paper, Bowker (2004) interviewed children ($n = 72$) from eight primary (elementary) schools about 1 month after they had been on a 1-day school visit to the Eden Project. Bowker interviewed three mixed-attainment groups of three children (aged 7–11 years) in each of the schools. Photographs taken inside the Eden Project were used to stimulate the children's recall and to facilitate the discussion. In discussing his findings, Bowker noted that

> …children enjoyed their visit to the [Eden Project] and were affected by the sensory experience of being immersed in such a profusion of plants from around the world. The children showed interest in the plants that were relevant to their lives but were often unsure of the relationship between plants, people and resources. (2004, p. 227)

Specifically, Bowker found: 'Even during a short visit [the children's] opinion of plants changed, they understood the link between plants to their own daily lives and took delight in finding out where chocolate came from' (p. 241). Bowker claims that the study 'highlights the need for teachers to integrate a visit to the EP within their school's curriculum, particularly in respect of prior preparation and mediation, in order to capitalize effectively on the children's experiences during their visit to the Eden Project' (p. 227).

While many of these studies, for obvious reasons, focused on short-term benefits, studies that identified long-term impacts are less common. An exception is a US study by Stefanie Pace and Roger Tesi (2004) that involved interviewing four men and four women between the ages of 25 and 31 years about their field-trip experiences while attending school from K–12 (age 17–18 years). Most of the participants revealed that they experienced 'enhanced camaraderie with fellow students, teachers, and chaperones [accompanying adults]' as a result of their experiences (p. 30). According to the eight participants, science and history concepts and knowledge were reinforced through experiences at museums, zoos and historical sites. Pace and Tesi concluded that

> …field trips that required hands-on activities seem to have a positive impact on student ability to recall information learned on the educational excursion, and students tend to enjoy this type of experience when compared to field trips that didn't encompass hands-on activities (p. 30).

James Farmer, Doug Knapp and Gregory Benton (2007) evaluated Parks as Classrooms, an environmental education program in the Great Smoky Mountains National Park, USA. The program focused on the impact of non-native species and humans on local biodiversity. The participants in the study were from a primary school (aged 9–10 years) from Tennessee, USA; 15 of the 30 students agreed to be interviewed a year after their visit. The authors reported that 'many students remembered what they had seen and heard and had developed a perceived pro-environmental attitude' (p. 33). This conclusion reinforces the argument made above that educational experiences that provide memories are important as they can form the basis for reflection on events that happen subsequently.

Moses Gostev and Francesca Weiss (2007) provide a case study of a primary school in New York City, USA. The researchers followed a class over two years, from kindergarten to grade 1 (6–7 years olds). When the class explored nature through direct observation of animals in the classroom, child-centered inquiry science, and school-sponsored field trips, 'not only did students develop scientific literacy and communication skills, they also deepened their understanding of their environment' (p. 48). The majority of studies carried out tend to focus on the science knowledge and skills end of the spectrum rather than the broader sustainability end. This is not surprising as teachers probably know more about science than about sustainability and might have relatively narrow expectations of the outcomes of fieldwork.

Other Outcomes

While most studies focus on the development of greater knowledge about the environment, an increasing number involve a more diverse range of outcomes. For example, Ruth Amos and Michael Reiss (2006) evaluated the impact of the 2004 London Challenge Residential Initiative which involved 51 schools from fi relatively deprived areas of London in sending groups of 11–14 year olds to field centres. The researchers studied 13 courses with 428 students from 10 schools (2 from each of the 5 areas). The students were given a pre- and post-visit questionnaire that assessed attitudes towards school subjects related to the field centre visit and the students' expectations and enjoyment of the course. Teachers who had escorted the groups were interviewed before and after the course. Focus-groups discussions involving students were held in five of the participating schools within 2 weeks of returning from the course. The authors found that participants

> surpassed their own expectations of achievement during the courses, and both pupils and teachers felt that the general levels of trust in others and the self-confidence shown by the pupils on the courses were higher than in school subjects. (p. 37)

Surpassing expectations, whether the teachers' or the participants', is a relatively common phenomenon. This is a rather worrying state of affairs if traditional schooling results in students failing to reach their full potential. This gap between potential and achievement in school and out of school has not been researched systematically and yet it might hold the key to challenging some of the barriers to taking students beyond the classroom.

Traditionally, evaluation and impact studies have tended to focus on a narrow range of outcomes resulting from educational experiences. An unusual approach to evaluating the impact of an outdoor experience was reported by Anja Whittington (2006). The participants in this doctoral study were a group of adolescent girls who took part in a 23-day canoe expedition as part of an all-female wilderness program in Maine, USA. Whittington interviewed the girls twice following the expedition, once 4–5 months afterwards and the second time after 15–18 months had elapsed. A range of other data-collection methods were used including ‘a focus group, a public presentation, parent surveys, journal entries, and other written materials created by the participants’ (p. 205). Whittington reported that the experience enabled the participating girls to challenge ‘conventional notions of femininity in diverse ways’, including (1) perseverance, strength, and determination; (2) challenging assumptions of girls’ abilities; (3) feelings of accomplishment and pride; (4) questioning ideal images of beauty; (5) increased ability to speak out and leadership skills; and (6) building significant relationships with other girls’ (p. 205).

On Pedagogy

Much of the research supports what is seen as good practice in terms of organising visits to locations beyond the classroom (Anderson and Lucas 1997). There is no shortage of advice for teachers about using the outdoors in practitioner journals. Anthony Fredericks and Julie Childers, for example, ‘have come up with a tried-and true planning timeline and a few suggestions to help make the next trip to the [sea] shore worthwhile’ (2004, p. 33). Much of their advice would tally with research findings, such as: ‘Effective field trips require planning, preparation, and follow-through upon returning to school as well as coordination between the host site, school, and chaperones’ (p. 33).

While much of the research has focused on the outcomes of field-trip and residential experiences, some attention has been paid to specific education practices. Research has contributed to shifting pedagogies both outdoors and during museum visits. The common practice of giving students activity sheets at the start of each visit has been found to be counterproductive by several researchers including Paulette McManus (1985). Janette Griffin and David Symington (1997) found that activity sheets could keep students on-task, but that they did not necessarily benefit science learning. In general, little research has focused on the design, impact or evaluation of specific aspects of pedagogy in out-of-the classroom education. This observation might explain why so much outdoor education is rather conservative in its approach and why environmental educators can be quick to adopt radical, though untested, approaches to education beyond the classroom.

Conclusions

Rosalind Driver (1989) argued that science learners benefit from teachers who present material in a variety of ways. Although classrooms are convenient, they cannot provide the diverse experiences that students can have in museums, aquaria, science centres or local parks. Visits to locations beyond the classroom offer students opportunities to learn new skills (Leinhardt and Crowley 2002), see actual specimens rather than models or photographs, and stretch their senses.

As opportunities for science learning beyond the classroom continue to grow in terms of numbers and sophistication, research also continues to show the potential benefits that can accrue. Although studies usually focus on benefits to individual students, there are other potential outcomes. If learners enjoy science more through seeing it in a wider context and develop an appreciation that science is a human activity, science education might be seen as more relevant and more appealing. As Annette Gough wrote:

> Rather than accepting the confines of traditional science education and its rejection of values and action which make it unattractive to many, the challenge is to change the science education curriculum so it can have a mutually beneficial relationship with environmental education. Not a simple task, but a worthwhile one – for all! (2002, p. 1213)

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Chapter 72
Informal Science Education in Formal Science Teacher Preparation

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Introduction

Science education reform efforts worldwide have called for the need for quality teacher preparation and professional development programs in recognition of the central role of teachers in promoting and improving science literacy. For example, a recent report from the European Union (EU) on science education recommends a significant long-range investment in transforming the professional development of those who teach science to sustain their science knowledge, innovative pedagogy, and their skills (Osborne and Dillon 2008). Professional development standards in the USA, the National Science Education Standards, call for teachers

> …to practice active involvement in scientific investigations; to be introduced to resources that expand their knowledge and ability to access further knowledge; to build on present science understandings, abilities, and attitudes; and to engage in collaborative science learning experiences. (National Research Council 1996)

Despite the worldwide call for reform in science teacher preparation that supports findings in the learning of science, many teachers report entering the classroom feeling inadequately prepared to teach science. Janet Kelly (2000) suggests that this situation could be attributable to a number of factors, including the didactic nature of the science courses that teachers have themselves experienced, or the disconnect between the teaching methods advocated in science methods courses and the textbook or lecture-based methods still practiced in many schools. As a result, there is an evident need for innovative and effective science teacher preparation and

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professional development opportunities. Kenneth Tobin, Deborah Tippins, and Alejandro Gallard (1994) argued that if systemic change is to be achieved, teacher education programs must alter the way teachers are prepared to teach science.

Researchers have suggested that one innovative way to transform science teacher preparation and meet the needs of science education reform is to make connections between informal and formal science learning environments. David Anderson, Bethan Lawson, and Jolie Mayer-Smith (2006) argue that in teacher preparation programs, connecting informal and formal science education may alter preservice teachers' views about the nature of science teaching and learning, build confidence, develop identities, and supplement learning that occurs in the formal setting.

Informal science learning settings have unique characteristics that potentially may be beneficial for formal science teacher preparation programs. Unlike the school-based science learning to which teacher interns are often exclusively exposed in teacher preparation programs, informal science learning can take place across diverse out-of-school settings. In this view, Lynn Dierking, John Falk, Leonie Rennie, David Anderson, and Kirsten Ellenbogen (2003) and also Leonie Rennie (2007) suggest that science learning is an ongoing, cumulative process influenced by diverse experiences across time and place, a perspective that has the potential to change the way teacher candidates think about what it means to teach and learn science. Informal science settings shift the focus away from performance-based measures in science content to a focus on developing aspects of the affective domain. Maura Lobos Jung and Karen Tonso (2006) and Kelly (2000) suggest that the focus on measures in the affective domain in informal science education may be influential in developing positive attitudes such as confidence to teach science and increased interest in science. The science content presented at informal settings such as aquariums and science museums is repeated more frequently than content in a formal setting, allowing teacher interns many opportunities to test different teaching methods. In contrast, interns in formal settings have limited opportunities (sometimes only one) to practice teaching a particular science concept. Further, a practicum experience in an informal education setting provides preservice teachers opportunities to see science inquiry in action. Teachers in informal settings must adapt the content presented to meet the diverse needs of heterogeneous groups visiting these settings in which members range in age, gender, learning needs, and interests.

Definitions

Rennie (2007) defined informal science education, in general, as the science learning that takes place in contexts outside of the formal school setting. Falk (2001) described this form of science learning as free-choice science learning, which is self-motivated, voluntary, guided by learners' needs, and engaged in throughout life. Valerie Crane (1994) defined informal science as "activities that occur outside the school setting, are not developed primarily for school use, are not developed to be part of an ongoing school curriculum, and are characterized by voluntary as opposed to mandatory participation as part of a credited school experience" (Crane 1994, p. 3). Informal science learning occurs in a number of out-of-school environments that include, but are not limited to the following: museums, aquariums, zoos, TV, radio, the Internet, and community-based programs. John Bransford, Ann Brown, and Rodney Cocking (2000) as well as Crane (1994) include the home environment as another context for informal science education, pointing out that interactions within families provide early science learning opportunities and establish a supportive learning environment.

Ideally, researchers have identified a number of distinguishing features associated with informal learning: learning is voluntary and self-motivated (Rennie 2007; Rennie et al. 2003), the content is often nonsequential (Hofstein and Rosenfeld 1996), learning is socially constructed and guided by the learner's needs and interests (Falk 2001), and there is no formal assessment (Rennie 2007). Practically, however, especially for community-based informal science education programs that seek to make connections with formal science learning in schools, these features often have to be adjusted to fit the constraints of the context; that is, most children's programs cannot be completely voluntary or self-motivated, given that adults most often schedule and transport children to activities, and informal science educators have had to show linkages between formal and informal curricula. John Falk and Martin Storksdieck (2005) explain that developers of informal education programs often recognize the socially constructed nature of learning and structure learning opportunities in these settings accordingly. Informal science programs, as a result, characteristically can provide opportunities for participants to interact with one another and guide their learning. These programs are also primarily concerned with variables related to the affective domain of learning. Therefore, Joyce Meredith, Rosanne Fortner, and Gary Mullins (1997) describe how the goals of many informal science education programs focus on fostering positive attitudes about science and improving confidence for doing science. Yehudit Dori and Revital Tal (2000) include encouraging individuals to participate in science as another central goal of informal science education.

Review of Literature

We report literature that includes components of informal science education in formal science teacher preparation, focusing on ways in which informal science education was identified as benefiting formal teacher education while also reporting perceived problematic aspects. Procedurally, we systematically searched the literature using the following key words: science teacher preparation, preservice teacher preparation, preservice science teachers, teacher education, informal science, out-of-school science, and free-choice science. We selected studies from multiple countries that focused on preservice professional development opportunities in a variety of informal learning environments including aquariums, community-based programs, science museums, and nature centers. We identified articles that incorporated informal science settings in a number of unique ways.

Benefits of Including Informal Science Education in Formal Science Teacher Preparation

Studies that have investigated the inclusion of informal science education settings in formal teacher preparation report a number of perceived benefits in developing positive attitudes (the value, interest, and excitement of science and the environment – including a respect for life, toward an open mind for change, confidence in teaching), pedagogy (the use of theory in practice, collaboration, teaching for all, classroom management, resource management), science skills (explore, observe, inquire, plan, evaluate, think critically and creatively, work both independently and socially, solve problems), and understandings (explanations for how the world works and the relationship between science and technology). For heuristic purposes, we report findings by their affective benefits, exposure to new teaching strategies, experience teaching in diverse contexts, broader perspectives on science teaching and learning, gains in science content knowledge, and development of professional skills.

Affective Benefits

Because the goals of informal science education are often focused on affective outcomes, informal science settings have a unique potential to impact preservice teachers' attitudes toward, and interest in, science. Preservice elementary teachers in Brian Ferry's (1995) study reported that a science center-based teaching practicum had a very high impact on their curiosity and interest in science. Participants commented that the informal environment made science fun and relevant to their own lives. Kelly (2000) found that many preservice teachers entered their science methods course with conceptions of science as boring and difficult to master. However, after participating in a science methods course, which included a practicum experience at a science and history museum, more than 90% of the preservice teachers indicated an increased interest in science on post-course questionnaires. David Chesebrough (1994) reported that an innovative science methods course taught at a science center improved preservice teachers' attitudes toward science teaching. Participants cited the hands-on focus of the science center, the enthusiasm and modeling of the instructors, and the unique resources available at the science center as positively impacting their attitudes toward science teaching.

With increased interest in science and improved attitudes toward science teaching, preservice teachers' experiences in informal science contexts can also lead to higher levels of confidence in science and science teaching. Research in teacher education has indicated that many elementary teachers enter the profession lacking the confidence and background knowledge essential to effectively teach science (Ferry 1995). A number of studies, however, have suggested that opportunities to teach and learn science in informal contexts can assist preservice teachers in this area. Anderson et al. (2006) found that a 3-week teaching practicum at an aquarium improved preservice secondary science teachers' self-efficacy and self-confidence in teaching science and in making sound educational judgments. Several participants noted that the aquarium practicum enabled them to overcome professional and personal struggles they had experienced in their classroom practica. The informal aquarium setting helped restore preservice teachers' interest in the teaching profession and confidence in their own teaching abilities. Similarly, Ferry (1995) found that a high percentage of preservice teachers reported that a science center teaching practicum had a high or very high impact on their self-confidence and confidence that they could understand science. He suggested that the nonthreatening and supportive nature of the science center was a significant factor in helping participants gain confidence. Further, preservice teachers in a science methods course that included a museum teaching practicum felt more qualified to teach science (Kelly 2000). Jung and Tonso (2006) studied the impact of museum and nature center teaching practica on preservice teachers, concluding that these contexts facilitated a unique sequence of experiences that promoted confidence. In these informal environments, preservice teachers had opportunities to observe hands-on instruction and see it modeled, to memorize lesson flow and content, to practice teaching, and finally, to repeat teaching the same lesson multiple times – an opportunity which is rare in formal classroom settings, but effective in reducing preservice teachers' nervousness surrounding science teaching. Another feature of informal settings that contributed to preservice teachers' confidence was the opportunity to work in situations with small student–teacher ratios. Brenda Spencer, Anne Cox-Petersen, and Teresa Crawford (2005) found that teaching elementary students in an informal afterschool program gave preservice teachers opportunities to work with smaller groups of students and feel confident that their interactions with individual students were meaningful. The lower student–teacher ratio also helped increased preservice teachers' confidence in terms of their perceived ability to assess student progress.

Another affective outcome that researchers have observed in preservice teachers who have taught in informal science contexts is an increased sense of autonomy. Because learning in informal environments tends to be more self-directed and less structured than in classroom environments, preservice teachers often have more freedom and opportunities for independent decision-making. In an aquarium setting, preservice teachers valued their higher level of independence as compared to their classroom teaching practicum, and teachers "noted that exploring new techniques was not encouraged, and could be in fact quite costly, in their classroom practicum" (Anderson et al. 2006, p. 348). The informal setting, as Ferry (1995) describes, can provide a fun, nonthreatening, and supportive environment in which preservice teachers can experiment with new approaches to science teaching. It has also been reported that preservice teachers felt less inhibited in museum and nature center settings and were free to develop their own teaching styles (Jung and Tonso 2006). This was also found in Spencer et al.'s (2005) study of an afterschool setting, in which preservice teachers worked in teams without the guidance of mentor teachers. Without an on-site supervisor, participants immediately had opportunities for leadership roles and to develop their own lessons and teaching methods. In addition, because participants in these studies were not monitored and assessed as in classroom teaching practica, nor were they expected to emulate the practices of one mentor teacher, informal settings allowed preservice teachers freedom to make decisions about their practices with less anxiety about meeting the expectations of others.

Exposure to New Teaching Strategies

Researchers theorize that informal science education settings may offer features that guide teachers to develop new teaching strategies, especially strategies that focus on active learning. In Anderson et al.'s (2006) aquarium-based study preservice teachers reported that the labs and programs offered at the aquarium allowed them to realize the advantages of hands-on science learning and the value of experiencing real science. Participants in Jung and Tonso's (2006) study reported benefiting from seeing hands-on strategies in action during their practica experiences at a museum and nature center and indicated plans for incorporating hands-on science in their future classrooms. In several instances, Jung and Tonso found that the informal practica experiences were the first time participants saw hands-on activities modeled. Janice Leroux (1989) investigated a preservice teacher program offered at a science museum in Canada and found that the freedom of museums facilitated the use of innovative strategies such as hands-on learning. Carol David and Bradley Matthews (1995) followed-up with teachers who participated in a museum internship. David and Matthews believed that experiences teaching in the museum would expose teachers to hands-on learning strategies that they could adapt for their future classrooms. Through analysis of data collected from surveys, David and Matthews found that preservice teachers, on average, reported using hands-on science activities 309 min/week compared to a reported 147 min/week by new teachers who did not participate in the internship.

In addition to experience with participatory science activities, the freedom offered in many informal science settings was found by researchers to allow teachers to experiment with other innovative strategies they can use in their future classrooms (Cox-Petersen et al. 2005; Spencer et al. 2005). As a result of this autonomy, preservice teachers in these programs experimented with inquiry-based teaching strategies and learned to integrate science with other content areas such as language arts and social studies. In Kelly's (2000) study, in which the preservice teachers interned at a local museum of science and history, on post-course surveys, the interns indicated intent to use constructivism and learner-centered activities in their future classrooms. Chi-Chin Chin (2004) found that a methods course which incorporated experiences at a natural history museum in Taiwan encouraged preservice teachers to apply flexible, non-lecture teaching methods, integrating strategies from the museum such as role-play, discussion, and writing activities. Further, the museum experience prompted teachers to consider the importance of using multiple methods for ongoing student assessment.

Participants in the informal programs reported learning teaching strategies for conducting and preparing students for field trips that are generally acknowledged as enriching students' formal science education. Joanne Olson, Amy Cox-Peterson, and William McComas (2001) used a science methods course to model effectively conducting field trips for preservice teachers. In collaboration with a zoo and a museum of natural history, instructors and museum staff introduced preservice teachers to education activities that they could use to connect learning from the informal setting to their classrooms. As a result of the course, teachers reported recognizing the importance of preparing students for field trips through the use of pre- and post-trip activities to facilitate learning. Similarly, Anderson et al. (2006) found that after a practicum experience in an aquarium, teachers recognized the importance of preparing students for field trips using pre- and post-trip activities that integrated the field trip with classroom learning.

Experience Teaching in Diverse Contexts

The diversity among participants of informal science education programs prompted some preservice teachers to develop differentiation strategies to meet the needs of all students. Specifically, student groups in informal contexts vary in factors including, but not limited to, age, skill, interest, socioeconomic status, and primary language spoken. For instance, preservice teachers in Cox-Petersen et al.'s (2005) study participated in an internship in an after-school program for students in need of supplemental academic support that integrated science with language arts. In a similar program, reported by Spencer et al. (2005), preservice teachers participated in the same after-school program, but instead focused on integrating science with social studies. Students in these programs ranged in age and spoke English as a secondary language. Due to the diversity among students of these programs, preservice teachers had to differentiate their lessons to meet the needs of all students in the program. Students also varied in age, prompting preservice teachers to develop multilevel lesson plans. The unique characteristics of these programs, such as collaboration with peers, the freedom of the program, and low student–teacher ratios, guided teachers to develop differentiation strategies.

Jung and Tonso (2006) found that in the informal science setting preservice teachers were able to spend more time actually teaching science and gaining experience with appropriate pedagogical strategies for diverse students than they did in formal classroom internship settings. Participants noted that they were enabled to learn more about the learners' backgrounds and how their science learning, cognitive development, and behavior progressed from younger to older grade levels.

Informal science teaching experiences in general, and the opportunity to teach diverse groups of learners in particular, can benefit preservice teachers by helping them by experience to build student management skills. Preservice teachers participating in museum-based teaching practica, for example, have the opportunity to observe many different teachers interact with and manage students. Anderson et al. (2006) found that observing teachers interact with students in an aquarium setting helped preservice teachers identify student management practices that were both effective and ineffective. They were also able to practice student management skills themselves, enabling them to understand the management strategies necessary during hands-on learning and in out-of-school settings. Thus, the experience of teaching in the informal setting gave preservice teachers skills that were transferable to the classroom, but also skills necessary for leading students in science learning outside of school.

Broader Perspectives on Science Teaching and Learning

Three studies have reported that experiences teaching science in informal learning environments can provide preservice teachers with a broader and deeper understanding of learning theories and how these may be translated into practice. Because of the interactive, self-directed nature of many informal settings, learners have unique opportunities to ask questions and construct knowledge for themselves. Anderson et al. (2006) found that observing science teaching and learning at an aquarium was several preservice teachers' first opportunity to truly see constructivism in use. Because preservice teachers were working with new audiences each day in the aquarium setting, they became especially aware of the need to uncover learners' prior knowledge and experiences and then help learners build upon these. Similarly, Kelly (2000) reported that participating in a science methods course that included a museum-based teaching practicum helped 96% of participants achieve a better understanding of constructivism and its implications for teaching science, and Jung and Tonso (2006) found that out-of-school teaching practica made the idea of constructivist teaching concrete for interns.

Kelly (2000) found that by teaching and learning science in a museum, preservice teachers came to value science and science learning as a process, placing less focus on finding all the right answers and more focus on actually doing science with students. This was particularly true when preservice teachers had opportunities to become side-by-side learners with elementary students in informal environments. Anderson et al. (2006) also reported that teaching in an informal setting helped preservice teachers develop broader epistemologies of science teaching and of more holistic views of education in general. In this case, the aquarium's focus on conservation education prompted preservice teachers to reflect on their own values and what was personally important to them include in their own teaching. They came to see science teaching as more than covering a prescribed curriculum, as also a way to highlight big-picture concepts, such as conservation, that they believed were valuable for students to understand. Anderson et al. concluded that participants were "clearly transformed and broadened their epistemologies and pedagogies of teaching" (p. 351). In addition, teaching in informal contexts could help preservice teachers become aware of how different learning environments influence science teaching and learning. Chin (2004) observed this increased awareness among preservice secondary science teachers in a science museum setting, noting that such awareness cannot be easily taught in the traditional science methods course.

Gains in Science Content Knowledge

Although not an explicit goal of any of the programs reviewed, the use of informal science settings for science teacher preparation may facilitate science content gains. Ferry (1995) found that teacher preparation at a science center guided preservice teachers to learn alongside student visitors to the center. Preservice teachers in the program self-reported content gains through responses to questionnaires administered after the program in the science center. Some participants in Chesebrough's

(1994) study also reported content gains. One participant, for instance, described being able to "relearn everything" (p. 32) as a result of the content in an innovative science methods course. Further, some participants reported improved science knowledge after participating in the program at the museum (Chin 2004). In the Jung and Tonso (2006) study, participants in a practicum experience in informal settings reported gaining scientific knowledge. Jung and Tonso reported that the benefit of content gains varied from participant to participant, depending on their background. Preservice teachers majoring or minoring in science areas experienced less notable gains than other participants. Although science content gains varied across the programs reviewed and the participants in these programs, the studies reviewed suggest that informal science teacher preparation programs might be influential in developing participants' science knowledge.

Development of Professional Skills

The characteristic collaborative nature of many of the informal teacher preparation programs guided participants in the reviewed studies to develop their professional skills. Informal science education settings often afford more opportunities for collaboration between teachers than formal school settings. Participants in the Anderson et al. (2006) study, for instance, noted these differences, describing the aquarium context as conducive for joint discussions and reflection among preservice teachers. Practica experiences in the formal setting, Anderson et al. suggested, typically involved a preservice teacher working with one mentor teacher in an isolated classroom. In contrast, at the aquarium practicum, preservice teachers worked closely with one another to share ideas and reflect on effective teaching strategies. In the after-school program studied by Cox-Petersen et al. (2005) preservice teachers worked collaboratively in groups of three to four to develop daily lesson plans. As a result of the collaboration, participants reported being able to share ideas and improve lessons through reflection with members of their collaborative team. Participants in the Spencer et al. (2005) study reported similar gains, stating the collaboration offered opportunities to learn from and support one another. The program reported by Leroux (1989) fostered a collaborative environment that includes the preservice teachers, university instructors, and museum staff. Through collaborative interactions, preservice teachers were able to share ideas and assess individual student progress.

The relaxed atmospheres offered at informal science settings were influential in providing preservice teachers with greater opportunities to reflect on their teaching practices. Preservice teachers in the Anderson et al. (2006) reported that the aquarium practicum experience prompted them to reflect and consider their philosophy of and values about teaching. In the informal practica experiences described by Jung and Tonso (2006), preservice teachers reported that the out-of-school settings provided repeated opportunities for teaching a lesson. The multiple opportunities to teach lessons helped teachers learn reflective practices to improve their lessons each time.

Another advantage of connecting formal and informal environments in teacher education was found to be the preservice teachers' gains in a professional knowledge base of community resources offered by informal settings such as after-school programs, museums, science centers, and aquariums. Jung and Tonso (2006) reported this gain, suggesting that one benefit of out-of-school settings for science teacher preparation is access to classroom resources that preservice teachers can begin to gather and adapt for their future classrooms. David and Matthews (1995) speculated that museums could provide teachers with necessary materials and equipment for implementing hands-on science activities in their classrooms. Chin (2004) recognized the importance of resources in the classroom and argued that informal settings are rich with resources for science teacher preparation and science methods courses should encourage preservice teachers to take advantage of these resources in their classrooms.

Problematic Aspects of Including Informal Science Education in Formal Science Teacher Preparation

Although informal science education settings may offer numerous benefits, several studies we reviewed identified various perceived problematic aspects of including informal science education in formal science teacher preparation. Many informal science contexts focus on only one or a few science topics, which limits the extent to which participants can gain extensive science knowledge (Jung and Tonso 2006). Chin (2004) argued that informal settings, such as museums, emphasize certain science content areas more than others (e.g., life science over physical science). The short period over which these informal science practices take place also limits the extent to which teachers can develop new skills (Leroux 1989). Jung and Tonso (2006) advised that practica in informal environments provided only limited opportunities for preservice teachers to develop classroom and time management skills and do not reinforce skills for transitioning between different subjects.

Several participants of the Jung and Tonso (2006) study recognized some of the limitations of the informal context, reporting that they were unable to make connections between informal practica and their formal classrooms. Similarly, Kelly (2000) reported that participants in her study also struggled to connect the teaching strategies learned in the informal context to the formal classroom setting. The preservice teachers reported that it was difficult to persist with the teaching innovations learned in the informal practicum because of a lack of support and encouragement from fellow teachers in the formal setting. Preservice teachers in the program described by Chin (2004) reported concerns about behavior management in the informal setting. Those preservice teachers also found it problematic to assess learning in informal settings. Other studies reported on the procedural and financial challenges of including informal science education settings in science teacher preparation programs. Preservice teachers in an elementary science methods course described difficulties in finding transportation to and from the science center (Chesebrough 1994) while another challenge of including informal contexts in formal teacher preparation was securing funding to support the innovation (David and Matthews 1995).

Implications for Science Education Researchers

The research to date suggests that informal science education may well offer a supportive component to formal preservice teacher education. Including this component in formal teacher education is not without its challenges, however. Some of these challenges in an informal science education component in teacher education program may be inherent limitations of a particular informal science education venue (such as a focus on a limited number of science content areas), or the unique nature of informal science education (such as the lack of a focus on formal assessment). Continued investigation in this area of research is therefore warranted. Some questions that require further investigation include:

1. How is the development of the professional identity of an intern as a teacher of science influenced by experiences in both formal and informal science education?
2. Is there a differential impact of connecting formal and informal science education on preservice of different backgrounds, and if so, for what reason(s)?
3. How does the length of duration of an informal science education internship in a formal science teacher education program influence the professional development of preservice science teachers?

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Chapter 73
Out-of-School: Learning Experiences, Teaching and Students' Learning

Tali Tal

Informal and nonformal learning, informal settings, outdoor learning, and free-choice learning environments are all common terms used to describe the variety of learning opportunities that are provided in out-of-school settings. Each of these terms has multiple meanings, justifications for use and antagonisms. For example, in the policy statement of the Informal Science Ad Hoc Committee, *informal science learning* is defined as "science learning that occurs outside the traditional, formal schooling" (Dierking et al. 2003, p. 108). However, this term is criticized as limiting other forms of learning that occur in everyday contexts as a result of the intrinsic motivation in free-choice situations and that are lifelong experiences. Although that Ad Hoc Committee rejected the term *Informal science education*, no alternative term has been widely accepted by the research community since then. The term *free choice* is an insufficient substitute as not all out-of school learning experiences provide choice for the participants (Bamberger and Tal 2007). Quite often, the learning environment itself cannot allow freedom of choice due to safety issues such as found in industrial plants (Hofstein and Kesner 2006), in research facilities (Tal and Morag 2007), or in many natural environments. Given that in this chapter I discuss only school field trips, the neutral term *out of school* (Rennie et al. 2003) that was used for suggesting a research agenda to the research community is general enough to describe all the types of activities by the target population (students) and by the location (not in the school).

By using the term *out of school*, a variety of learning environments can be examined. With this term, predetermined ideas about how formal the activity is (Hofstein and Rosenfeld 1996); who controls the objectives and means of learning (Heimlich 1993); whether it occurs within buildings or in the outdoors (Rickinson et al. 2004); or

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the degree of freedom as perceived by the learner (i.e., free choice) (Falk 2001) can be avoided. My intention is to examine three main features of students' activities in out-of-school learning environments: freedom of choice, the way the educational activity is carried out and students' learning. This will be done with respect to a variety of environments such as science museums and science centers (SMC), natural history museums (NHM), the outdoors, zoos and aquariums (ZA), botanical gardens and industrial plants. Few general patterns will be presented, learning (and other) outcomes will be discussed and eventually, I will identify common and unique challenges.

Characteristics of Out-of-School Learning

The research literature on out-of-school learning deals with many characteristics of learning. Museums for example, are perceived as places where people "construct personal meaning, have genuine choices, encounter challenging tasks, take control over their learning, collaborate with others and feel positive about their efforts" (Paris et al. 1998, p. 271). Learning in out-of school settings is seen as idiosyncratic (learning is personal), contextualized, and as a process that takes time (Falk and Dierking 2000). With respect to class visits to museums, Janette Griffin (2007) argues that ill-defined objectives, lack of preparedness, and poor pedagogy might hinder students' learning.

In this chapter I focus on three main features of school field trips to various settings: (1) the degree of choice given to students for exploration and learning that is driven by their own interest and motivation; (2) the type of teaching, explanation, and mediation, which is provided by the informal institutions and by teachers; and (3) the learning that occurs during these field trips. Each of these characteristics will be presented in detail. As the largest bulk of literature is associated with museums, there will be more examples of research that has been conducted in museum visits than examples of field trips to other settings. I believe that the research literature better reflects the feasibility of carrying out research in museums, which is easier than doing research in other settings such as the outdoors. Therefore, more field trips are documented in museums compared to the outdoors. In Israel, for example, in a recent survey of out-of-school activities, we found that 25–33% of out-of-school activities occur in the natural environment, 15–20% in museums, 10–20% in historical and archeological sites, 5–10% in zoos, and 5–10% in factories, with some difference associated with the grade level (Morag and Tal 2009).

Freedom of Choice

Since 2001, *free-choice learning* is the term which is widely associated with visits to informal (science) institutions (ISI). The term emphasizes the nonsequential, self-paced, and voluntary nature of learning, and it recognizes the importance of the physical and the sociocultural contexts of such learning (Falk 2001). To challenge possible criticism, John Falk (2001) has argued that free-choice learning is relative rather than absolute and that perceived choice and control of learning by the learner are the important issues. “To qualify as free choice learning, the learner must perceive that there are reasonable and desirable learning choices available, and that he or she possesses the freedom to select or not to select from among those choices” (p. 8). It is clear that any voluntary and self-paced visit to a museum, an aquarium, or a botanical garden allows the individual or a family to choose the sequence, time spent, dialogues they maintain, and any other activity. However, is this the case with school visits? Alternatively, we can ask to what extent the feature of choice is relevant while seeking meaningful learning in out-of school settings? It is evident that a school field trip is different from an individual or a family visit. A group of 20 or even 30 young students needs some guidance and the teachers are expected to control their students either to maintain good behavior or to meet certain learning goals. This necessarily means reducing the freedom of individuals in the group. Yet, many studies indicate that students learn better when they are provided with choice (Falk and Dierking 2000) and that some degree of choice is expected and appreciated even in school visits (Rennie and McClafferty 1995, 1996) by both teachers and students in order to have a positive experience.

Teachers who take their students on field trips are often concerned with how to manage the students, the activities they planned, and the time allocated to the visit and its components (Griffin 2004). Teachers are often concerned about the learning tasks their students should be engaged with (Griffin and Symington 1997) or about worksheets they need to complete (Kisiel 2003). Many visits are led by museum educators (i.e., docent, guide, explainer, facilitator) who lecture, explain, and ask questions but rarely allow the students any choice (Bamberger and Tal 2007).

In studying four natural history and science museums, Yael Bamberger and Tali Tal (2007) found that the museums presented a range of choice opportunities spanning from non-choice to free-choice visits with some patterns of limited choice in between. In that study, more meaningful learning was associated with the limited-choice pattern that allowed the students to explore the exhibit with some guidance or support provided by a learning task that was related to the visit theme, or by boundaries within the exhibit that prevented the students from cruising between halls and spaces. Bamberger and Tal asserted that the activities with limited choice served as mediation tools that scaffolded the students’ learning. A similar pattern was identified by Tina Jarvis and Anthony Pell (2005) in their study of school visits of hundreds of students to a national space center in the UK, in which they found that “children needed adult guidance as they found it difficult to make choices about what to do and were often overwhelmed by the wealth of activities” (p. 60). Furthermore, Jarvis and Pell argued that tasks that limited the students’ exploration to specific exhibits (i.e., limited space choice) were more effective than allowing the children to explore the entire science center with long lists of questions.

The next issue is to what extent the different out-of-school settings are similar with regard to the freedom of choice. One of the most cited studies of outdoor learning, since the 1990s, that focused on geological field trips emphasized the importance of well-structured learning activities in the outdoors following a careful preparation carried out in class (Orion and Hofstein 1994). In their study, Nir Orion and Avi Hofstein have presented the field activity within the classroom sequence, and showed how the outdoor activity helped students to give meaning to abstract scientific ideas studied in class. In a different setting, and with younger students, Jarvis and Pell (2005) indicated the contribution of well-designed role-play at the space center to students' memories and attitudes toward science. In the exhibit area of the space center, they found that more focused play occurred where the children played with the items as intended. This occurred when an adult explained what to do and took an interest in the children's activity. Léone Rennie and Terry McClafferty (1995, 1996) have argued that teachers should integrate visits with their teaching program in ways which complement the learning activities in school. However, students should get enough time to explore and interact with an exhibit and to socialize with each other (Rennie and McClafferty 1995). This fragile balance between task-oriented and student-oriented visit is the focus of many studies of school visits to natural history (Cox-Petersen et al. 2003; Tal and Morag 2007) and science museums (Griffin 2004). These studies imply that it could be that the circumstances of the organized school visit determine the extent of choice provided. These circumstances include the teacher's objectives and preparation, the way in which the students are prepared, the specific characteristics of the institution and the constituents of the exhibits, whether professional explanations/learning activities are provided and whether these activities are games and simulations or traditional worksheets.

An important factor that affects the students' choice has to do with the setting. Letting students explore a museum exhibit by themselves is not similar to a free exploration of geological formation along a canyon's cliff, or exploring a wetland habitat of a swamp, where students can get injured or harmed in many ways. Zoos, for example are safe environments, and their living exhibits encourage free-choice exploration. Anyone who tried to take an organized group of students employing the "walk and talk" pattern in which explanations about the animals are given must have experienced a great competition with the extremely interesting happenings around them. Although one would assume zoos would allow more free-choice opportunities to school groups than a field trip in nature, the research literature does not necessarily support this assumption. Even what was expected to be a free choice learning in a New Zealand zoo was quite structured with very little opportunity for free exploration of the students (Toffield et al. 2003). These researchers claimed however, that the constituents of the environment are of free choice, and their view is supported by Falk (2001) who highlighted the idea of perceived choice (by the visitors). Yet, the structured visit to the zoo, which was successful and enjoyable hardly allowed the students any moment of individual exploration as it was not part of the planned activity. In another study, in the UK, the authors argued that visits to a zoo and a natural history museum are missed opportunities because the visit was not structured enough and neither focused on specific learning goals nor did it employ a pedagogy that encouraged the students to do thoughtful work (Tunnicliffe et al. 1997). Although this study was carried out before the idea of free-choice learning was suggested, the researchers claimed that "experience with subsequent discussion and reflection may lead to learning. Experience of itself, whilst highly enjoyable, is overwhelmingly a missed opportunity when schools and museums fail to capitalize on its learning potential" (p. 1053).

The findings of Sue Dale Tunnicliffe, Arthur Lucas, and Jonathan Osborne (1997) are supported by another study of three natural history museums and a zoological garden in Israel, in which the authors found that the more meaningful learning outcomes were reported by students who visited the zoological garden that unlike the NHM allowed only no-choice guided visits (Bamberger and Tal 2008b). The researchers referred to possible factors that could have contributed to this difference. They suggested that living animals draw more attention and emotional engagement than museum exhibits, and that facilitators at the zoological garden, who were graduate students shared their personal experiences with the visiting students, which made them more enthusiastic. These two factors could have contributed to the more meaningful learning despite the fact that no choice was given to the visiting students.

In conclusion, the idea of perceived choice and control by the learners is important and has contributed a great deal to our understanding of individual and family visits, and to lesser extent, of school field trips. Yet, it is clear that other factors of the visit are no less important, and in the context of school visits that have different objectives than the family visit, it is not clear whether and to what extent choice and control determine the meaningfulness of the field trip.

Ways in Which the School Visit Is Facilitated

Two types of school visits are described in the research literature: in the first, the teacher prepares and leads the visit herself (Lucas 2000). In the second, a museum educator (i.e., explainer, facilitator, docent, guide) carries out the visit (Price and Hein 1991; Tal and Morag 2007). Regardless of who facilitates the visit, the teachers are the ones who usually plan taking their students to an informal institution and are held responsible for having certain objectives for the field trip. Teachers' objectives include conceptual learning, enrichment, social and emotional engagement, improving attitudes to science, changing pace, reinforcement of a specific content, and merely fun (Rennie and McClafferty 1995). To meet their goals, teachers need to prepare their students for the field trip, and carefully plan the learning experience within some type of framework that addresses the unique features of the environment (Gilbert and Priest 1997; Hein 1998).

Unfortunately, with the exception of a few studies that report exemplary work of teachers, the common picture is of teachers, who avoid proper preparation of their students and poorly plan the learning activities at the museum. At most they deliver worksheets that aim mainly at keeping the students busy with recording of what they see at the museum or plan school-like tasks that do not take advantage of the rich environment (Griffin and Symington 1997). In a study that compared museum visits of a few classes and their teachers, Jarvis and Pell (2005) have found that the teacher's preparation and function throughout the visit had an effect on students' engagement and science enthusiasm as well as on their anxiety. Tali Tal and Laura Steiner (2006) who studied 144 teachers visiting one science museum found that the majority of the teachers made only administrative contact with the museum. They found as well that more secondary school teachers were concerned about the science content and the pedagogy compared with elementary school teachers. A minority of the teachers reported substantial involvement during the visit, which was led by a museum educator, and this pattern was reinforced by observations of about 40 teachers. Similar patterns were reported by Janette Griffin (1994). This limited involvement of teachers was observed and reported as well after following 30 school visits to four natural history museums (Tal et al. 2005). The majority of the teachers took either a passive role or helped the museum staff monitoring students' behavior. Jarvis and Pell (2005) and Tal and Steiner have identified a few patterns of teacher (or adult) function: passive or manager, who is responsible mainly for the timetable; controller of behavior and administrative helper; and active – who mediates, encourages the students, reads labels, asks questions and plays as a role model. With respect to teachers' visit plans James Kisiel (2006) found three major patterns of teachers' action plans ranging from well-defined to undefined plans. Unlike Janette Griffin and David Symington (1997) who identified mainly task-oriented teachers, Kisiel stressed that more teachers seek ways of engaging their students in museum learning by employing informal strategies than teachers who use traditional teacher-centered strategies.

In many out-of-school settings, professional staff is leading the school visit. Although there are many forms in which informal educators facilitate the visit, commonly, an experienced adult, working at the ISI who is not known to the students meets them when they arrive at the ISI and takes the lead at a certain point. As indicated earlier, the schoolteacher can take various roles at this stage, ranging from active mediation to monitoring behavior, or even taking a break and going away for a while. In museums, the staff member can either teach the students about the exhibits, or use the exhibit to teach, illustrate, or amplify scientific ideas that the students learn in school or ones that are interesting for them. This difference is usually determined by how the visit was planned and coordinated by the teacher and the museum staff. Various studies have found that task-centered and guide-centered strategies include lectures (Tal and Morag 2007), long explanations, worksheets and so forth (Cox-Petersen et al. 2003; Toffield et al. 2003). Quite often the explanations do not address the students' prior knowledge and experiences; there is frequent use of scientific jargon; the museum educators make efforts to teach many scientific ideas during a short time visit; and they tend to have discussions with the students only to a limited extent, using mainly simple recall knowledge type of questions. As Leona Schauble and her colleagues (2002) argue, the educators enjoy the challenge of helping students learn (in museums), but the energy and resources devoted to deepening learning may "be wasted, or at best, underexploited" (p. 449) because of inadequate use of proper pedagogies.

Recently, there were several studies that indicated better attempts by informal educators to address learning theories in general and the literature on learning in museums in particular. Lynn Tran (2007) for example, found substantial evidence for creativity, complexity, and skills involved in teaching science in museums. She revealed that museum educators were attentive to students' needs and tended to adapt their preplanned activities to better suit the visiting students. However, it is worth noting that Tran studied only four experienced museum teachers, and that the lessons she studied were held in classrooms within the museum and not in the museum exhibit. In an attempt to use worksheets in a different way than the traditional, Marianne Mortensen and Kimberly Smart (2007) have analyzed tasks presented in museum worksheets and concluded that tasks that are designed to promote and scaffold learning affected the students' on-task behavior and increased curriculum-related conversations. Unlike Bamberger and Tal (2007) who defined levels of choice with respect to the overall pattern of the learning activity, Mortensen and Smart associated levels of choice with the number of possible responses. Yet, they reinforce Bamberger and Tal's conclusions that balancing freedom of choice with scaffolding students' learning best affect meaningful learning at the museum. David Anderson, Bethan Lawson, and Jolie Mayer-Smith (2006) in Canada and Tali Tal and Orly Morag (2009) in Israel reported attempts to employ student-centered strategies in an aquarium and an ecological garden through reflective practice of pre- and in-service teachers who functioned as informal educators. In both places the participant educators carefully designed their teaching based on the research literature.

In outdoor settings, the need to control students' behavior puts further challenge on educators. Walking along narrow trails is a physical challenge that could impede any pattern of free interactions among students and could affect their overall enjoyment. In a study of educational activities in nature centers in Australia, students reported that driving to the site, walking, learning activities, and fears of creatures were their least enjoyable component (Ballantyne and Packer 2002). Following the field trip the students provided positive responses about: being able to choose what to do during the excursion; learning outside of the classroom; learning together with friends; seeing something new; and being able to touch plants, animals, and birds. The students gave their lowest ratings to activities such as measuring water quality, listening to or reading stories about the environment, and using activity sheets to help learn about the environment. Although the educational activities were not described in the article, the students' data make it clear that features other than the structured learning activity were more appealing to the learners. Similarly, Katherine Emmons (1997) who studied 5-day educational program at a wildlife sanctuary in Belize revealed that shared experiences of students and teachers' modeling played a major role in learning. The educational program included hiking, night walks, group discussions, a lecture of a guest speaker, and an optional action project. Yet, the program was intensive and included a small number of volunteering participants. In studying educational activities in nature parks in Israel, Orly Morag and Tali Tal (2009) found that the vast majority of educators used many objects to explain abstract phenomena such as geological formations, watersheds, plant reproduction, and so forth, but failed in tying the field-based experiences to the students' own experiences, and they rarely engaged the students in small group activities or discussions. Moreover, in the observed field trips, students could not choose between different learning activities. In a review of outdoor learning, the authors imply that students' learning styles could affect their preferences to teacher-led activity versus student individual or group work (Dillon et al. 2006).

Students' Learning in ISI

To what extent is students' learning in informal settings similar to formal learning in schools? What are the expected learning outcomes at the museum/aquarium/nature park? To what extent do field trips improve or affect classroom learning? Should learning outcomes at the museum be viewed and evaluated using different lenses than used in schools? All these and other questions should be addressed in discussing students' learning in out-of-school settings. Although much past research aimed at showing how field trips contribute to conceptual learning, in the last two decades field trips have not been seen as a means to improve school-based learning (Rennie and McClafferty 1996). Rather, field trips are viewed as an excellent way to enrich students' experiences, motivate them to learn science, encourage lifelong learning and expose them to future career options (Hofstein and Rosenfeld 1996).

It is acknowledged that the museum experience is idiosyncratically related to the visitor's personal and social context and that it takes time to process the learning experience (Rennie and Johnston 2007). In the recent decade, there has been wide agreement that more diverse outcomes such as motivation, curiosity, interactions, and discourse should be viewed as learning. The contextual model of learning suggested by John Falk and Lynn Dierking (2000) is based on the notion that learning is not a process of absorbing transmitted knowledge. Rather, learning in general, and in out-of-school contexts in particular involves personal prior experiences and knowledge. It is associated with physical characteristics of the learning environment and it is enhanced by social interactions among learners. These social interactions are a central constituent of learning according to the sociocultural theory (Rogoff 2003), which became the leading theory in respect to learning in informal settings, for it allows learners to carry out dialogues with each other and with more experienced adults and interact with their environment in multiple ways (Ash 2002). It is reasonable to expect that museum exhibits or the outdoors that do not require students to sit in rows, and change classes every hour, allow and promote social interactions, sensual experiences, and a variety of opportunities to express individual experiences. In a recent review of school field trip literature, Jeniffer DeWitt and Martin Storksdieck (2008) stress that only few studies have focused on affective outcomes of field trips. They suggested that affective outcomes such as increased motivation and interest, or improved attitudes toward a topic might have greater long-term cognitive impact than factual knowledge that tends to disappear after a short time.

Diverse outcomes and the long-term impact of museum visits were found by studying a few natural history and science museums (Bamberger and Tal 2008a, b).

These included content, social, and interest-oriented outcomes. The researchers have argued that students connected what they learned at the museum to prior school-based and out-of-school knowledge even when the museum educators did not make any attempt to connect to such knowledge. The students indicated personal relevance of the visit, emotional engagement, and expressed strong willingness to visit a museum again. Following Falk and Dierking (2000) and Avi Hofstein and Sherman Rosenfeld (1996), all these could be viewed as learning outcomes. In the long term, students strongly remembered their personal interactions with other students, and those they had with the museum educator, referring to specific dialogues and topics. They eagerly anticipated another visit to a/the museum and to things they learned that were related to out-of-school knowledge. In their review, DeWitt and Storksdieck (2008) address other studies indicating strong affective outcomes that contribute to learning. They suggested that although the cognitive gains of the museum visit are not clear due to many interfering factors, the out-of-school experience adds to a person's repertoire which can be used to interpret future experiences.

A variety of learning outcomes of outdoor fieldwork is reported by Stuart Nundy (1999) who highlighted the outcome of gaining higher-order thinking capabilities that is enhanced through challenges such as group work, talk, control of learning, and thinking and talking about learning. Moreover, Nundy suggested that the cognitive gain is beyond the specific subject area and affects thinking processes in general. He argued that it is the interaction of affective and cognitive development which enhances the overall learning. Integrating cognitive, affective, and social gains and getting practical experience were suggested by Martin Braund and Michael Reiss (2006) who listed five learning outcomes of out-of-school settings: (1) improved development and integration of scientific concepts; (2) extended and authentic practical work; (3) access to nonschool material and to "big" science; (4) improving attitudes to school science and stimulating further learning; and (5) social outcomes, collaborative work, and responsibility for learning. Yet, they concluded by warning that "if we get it wrong" not only will we not use the high potential of out-of-school learning, we might keep losing good students from science and even worse – the very essence of school science will be questionable by decision makers (p. 1386).

Outcomes of outdoor learning were reviewed as well by Justin Dillon et al. (2006), who cautiously reported the effectiveness of outdoor environmental education programs from various countries. Yet, they argued that the research findings on sustainable pro-environmental behavior and students' attitudes toward the environment are somewhat inconsistent. In a comprehensive review of outdoor learning (Rickinson et al. 2004), the authors report many research findings of positive cognitive, affective, and social impacts. In many of the studies reported in that review, outdoor learning is strongly connected to pedagogies that promote active learning, self-control, real-world experiences, group work, inquiry, and so forth. This reinforces the notion that the physical environment alone cannot make a substantial impact on learning if the appropriate pedagogy is not considered. In a case study of a particular school from Israel (Tal 2004), it has been shown how a school-based curriculum in environmental education was a collaborative endeavor of the school and the community that took an active part in planning the curriculum and the learning activities, in enacting the project-based and field-based activities, and in carrying out the authentic assessment system. This comprehensive effort that made use of the outdoors through the employment of sociocultural pedagogies made an impact on the school, the parents, and the students (Dori and Tal 2000).

So far, it is clear that students' learning in out-of-school settings has different characteristics than classroom-based learning. It is less structured, less sequential, it occurs in a short time period, it is influenced by physical features, and allows more interaction among learners and facilitates interaction with adults (e.g., teacher, facilitator, chaperones). The learning outcomes, as discussed in the research literature are diverse: cognitive gain, conceptual learning, and improving thinking skills as well as affective, social, and behavioral gains that could further affect cognitive learning. Two points have to be made with regard to outcomes of out-of-school learning. The first is that despite wide acknowledgment of these learning outcomes, there has not been much study on noncognitive outcomes that involves a large number of participants across settings and institutions. The second point is with regard to how the out-of-school learning is facilitated. As noted in the UK outdoor learning review (Rickinson et al. 2004), "Poor fieldwork is likely to lead to poor learning. Students quickly forget irrelevant information that has been inadequately presented" (p. 29). Consequently, assessing students' learning in out-of-school settings is an important issue that has to be discussed here.

Unlike schools in which formal tests take place, out-of-school settings have almost no consistent assessment of learning. The number of studies that aimed at measuring learning is rather small, and the majority of these studies focused mainly on conceptual learning. In light of all the knowledge on out-of-school learning, which is discussed in this and other chapters in this book, it is clear that any coherent assessment should address the variety of learning outcomes, and therefore examine the students' thinking skills, their group work, motivation to learn science and their science-related identity, their understanding of the nature of science, their personal growth, and many other relevant variables. Rennie and McClafferty (1996) indicated that any attempt to measure learning from a museum visit should recognize the unique experience each visitor has and, therefore, this would be the antithesis of the pretest–posttest design that assumes a single experience for all learners. Any identical measure, according to Rennie and McClafferty can be effective only in highly structured visits to particular exhibits. The advantage of open-ended questions about what the visitor has learned is that each visitor can refer to specific things and can address cognitive as well as noncognitive outcomes. The limitation is the difficulty to assess depth of learning.

It is clear that only comprehensive assessments that make use of various instruments could shed more light on the various outcomes that are beyond improvement of conceptual knowledge. Furthermore, studies that compare learning across informal settings and that involve a large number of subjects could add to our understanding of the range of learning outcomes of the out-of-school learning experience.

Summary

In this chapter, I examined two issues that are widely discussed across the informal science education literature: freedom of choice and learning in out-of-school settings. The third issue, how the visit is facilitated is associated mainly with school visits to ISI. Although the idea of free-choice learning is appealing as it reflects the common visit to an ISI by a family group or by individuals, it is more complex when a group of students is going on a field trip. The objectives of a school visit are different than the voluntary visit. Students are not asked if they want to have a field trip, and commonly, they do not take part in planning the learning experience. Teachers either have curriculum-related objectives or have vague ideas about the visit objectives (Rennie and Johnston 2007), and they are often concerned about letting their students wander around with no purpose. Consequently, they (or the museum educators) use structured activities to engage the students. The balance between well-defined and ill-defined tasks, between scaffolding, structuring, and freedom, and between student-centered and task-centered activities is subtle. The research literature reflects the search for good models that will support the students, and at the same time, allow them to experience the features of the environment, which is different from their everyday school environment. I believe that more empirical studies that will look specifically at choice opportunities in different settings and the way they affect various aspects of learning will contribute to our understanding of the important feature of free choice environments.

The mediating role of adults is widely discussed in the informal science education literature. According to the sociocultural theory that strongly influences our understanding of learning in informal settings, meaningful learning occurs in rich physical and social environments (Ash and Wells 2006). Mediation, which is provided by objects, symbols, and humans is a central idea initially brought up by Lev Vygotsky (1987). Vygotsy's idea of Zone of Proximal Development (ZPD) is particularly helpful for understanding learning that occurs in nonschool environments as these environments are characterized by mediation provided by the physical objects as well as by people (i.e., fellow students, teachers, chaperones, and museum educators). The notion that collaborative social interactions promote learning and social construction of knowledge (Brown et al. 1989) has contributed a great deal to science education research in museums. In turn, this has also elevated research in schools (Rennie and Johnston 2007).

In order for an activity to be collaborative knowledge building mediated by artifacts and dialogues, students should not get simple answers determined in advance. Rather, they should negotiate with others in order to find complex answers to questions and in this way their expertise is distributed (Ash and Wells 2006). According to the sociocultural theory, learning is seen as a system of participatory competencies and activities, which means that an individual can participate in a particular group or world in an active way (Leinhardt and Knutson 2004). This is tremendously important for investigating the way the school field trips are carried out, and answering questions such as to what extent students discuss complex questions in small groups. Or in what ways adults function as mediators and encourage students' dialogues. As discussed earlier, it is rather clear that whereas the sociocultural theory can explain family visits to museums, aquariums, and zoos, organized activities for students too often look like efforts to transmit factual knowledge, or as efforts of teachers to manage and control their students' random cruise between the museum halls. Hence, the main challenge of ISI and teachers is to collaborate in order to utilize the advantages of the school field trip and push forward the opportunity for students to socially, emotionally, and cognitively interact with other students, with adults, and with artifacts to promote (lifelong) learning. Teacher training programs and museum-based professional development should emphasize the development of working relationships and building multiple bridges between schools and ISI in order to promote learning that encourages students to actively explore, question, debate, and be skeptic and emotional while being engaged in nature, museums, zoos, aquariums, botanical gardens, and arboretums.

Finally, it is clear that the type of learning that occurs in out-of-school settings is complex and it involves cognitive, affective, and social aspects and multiple and interrelated outcomes. Despite the growing interest, the majority of studies that focused on learning in informal settings have focused on voluntary visitors and the research literature on the multiple outcomes of students' out-of-school learning is limited. Although various studies have focused on cognitive outcomes, they hardly looked across different settings such as nature excursions and museums, or even at different museums. There are few studies that consistently examined cognitive as well as affective outcomes that support the effort associated with taking students to field trips (Rickinson et al. 2004). Overall, more intervention studies are required, in which teachers can be prepared and supported in planning a meaningful learning experience in ISI, and students' various learning outcomes in a variety of choice opportunities can be detected. Large-scale research is necessary especially in outdoor settings that are rarely studied, where diverse sensual experiences and physical challenges could affect students' engagement, and safety issues can determine the arrangement of the field trip.

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Chapter 74
Learning Beyond the Classroom: Implications for School Science

Peter Aubusson, Janette Griffin, and Matthew Kearney

Young people learn outside school, beyond the classroom. Much of the science that they learn comes from relatively informal experiences. The ideas and thinking that derive from daily experiences, conversations, curiosity, watching and listening are difficult to trace. However, we are fortunate that there is a significant body of research that has investigated the learning experiences of children and adolescents in a variety of settings beyond the classroom. These are sometimes referred to as informal settings but many include a variety of activities ranging from relatively formal and structured to entirely informal and ad hoc. We believe that much can be learned from a consideration of the way children and adolescents operate in these settings and that the patterns of engagement that have been observed have deep, fundamental implications for learning in science classrooms. It is impossible here to consider all the various fields in which learning beyond the classroom occurs. We focus on broad fields of research of adolescent experiences: first in visits to institutions such as museums[1] and zoos; second, in technology-mediated environments of the digital generation; and thirdly, in science research and display activities (e.g. science fairs). These fields have been selected in part because the authors have been conducting research in these areas and have, in recent conversations, come to realise that despite their diversity as sites of learning, the patterns of engagement of children and adolescents in these environments have much in common. Hence, we are asking whether they exhibit features of science learning that might be productively exploited in a traditional science learning environment – are schools capable of the essential changes that might facilitate their appropriation? Here we hope to provoke consideration of this possibility.

[1] The word museum is used to encompass a wide variety of informal learning settings such as zoos, gardens, science centres, museums, etc.

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Learning in Institutions Beyond School

Out-of-school contexts such as science centres, botanic gardens, museums, field study or industrial sites are of particular interest because they are well researched as learning environments. Consequently, they provide clearly outlined learning approaches that can be adapted for classroom teaching and learning. One of the significant features of these environments is the ways in which '…museums have retained the potential to engage students, to teach them, to stimulate their understanding, and most important, to help them assume responsibility for their own future learning' (Gardner 1991, p. 81). This is not intended to imply that the museum visit is intrinsically and invariably a rich learning experience. Rather the body of evidence suggests that when natural processes of curiosity and exploration underpin family, and even school visits, positive learning outcomes are likely. Here we first report on informal, typically family visits to sites and then consider examples of how the natural patterns of engagement of family and similar visits have informed developments in the realm of the school group visit.

Studies of visitor conversations have revealed the nature of learning when people voluntarily visit museums. Gaea Leinhardt, Kevin Crowley and Karen Knutson (2002) and others present a significant suite of findings, derived from a sociocultural perspective, that inform the ways in which meaning making occurs through visitor conversations in museums. Findings illustrate the ways visitors interpret and enfold their museum experience into their lives (Leinhardt et al. 2002); how the depth and analytical content of conversations varies according to their entering narrative (Abu-Shumays and Leinhardt 2002), and the ways in which personal identities are influenced during visits (e.g. Leinhardt and Gregg 2002). All of these projects reveal that museum conversations are centered on learning within a social context. More specifically, studies by Sue Allen (2002) at the Exploratorium and Janette Griffin (2007) at various Australian museums have found that the proportion of 'learning talk', when students were moving freely in the museum, to be about 83–90% of the total time spent in conversation.

Many studies have revealed that students value the autonomy and independence that comes with their learning in informal settings as well as opportunities for orientation to both the topic they are investigating as well as time to become accustomed to a new learning environment. A consistent finding from school visits to zoos, natural history museums, and science centres has been that students' views of their own learning are entwined with their social environment and that visiting in small groups can provide optimal contexts for sharing information. They associate new knowledge with social value. When someone has seen something new they become special and can tell others about it; and fun seems to be more likely when associated with a sense of mastery and control (Falk and Dierking 2000; Paris 1997).

These findings emphasise that students enjoy learning and engage in socially mediated learning activity when they have choice and control over what they are doing (Griffin 2004). Yael Bamberger and Revital Tal (2005) unpacked this perspective further, by studying the learning of students in museums, grouping them into four levels from no choice to free choice. They found that provision of even limited choice helped students to develop their natural curiosity with substantial engagement and learning outcomes.

Despite these findings, all museum encounters do not lead to valuable learning. Particularly in the case of school groups, museum visits are not always excellent learning experiences, many aspects of the preparation (both teacher and students), planning, or activity types can lead to poor learning situations (Kisiel 2003; de Witt 2007). However, in informal settings, cognitive and affective learning can enhance each other. School-oriented distinctions between education and enjoyment can be less apparent in informal settings, when opportunities are provided for personal choice of learning through social engagement.

Learning science can be and often is intrinsically self-motivating, emotionally satisfying and personally rewarding. People learn when they are in a supportive environment, involved in meaningful activities, without anxiety, when they have choices and control over their learning, and when the challenges of the task meet the person's skills (Falk 2006). When students are given the opportunity to clearly understand what and why they are learning, to choose their particular aspects of the topic and ways to learn and to see a value and use for the learning, then intrinsic motivation is heightened and deep learning is more likely to occur. Students become engaged in learning and develop interest in the world around them when they are:

- Dealing with things/ideas that are real, important and relevant to them
- Manipulating and exploring real things and phenomena
- Dealing with ideas that have meaning for them
- Working with others, talking and sharing ideas
- Participating in learning based on their real experiences
- Working with the teacher, not for the teacher
- Given opportunities to take ownership in what and how they are learning
- Finding their own, real answers (Griffin and Symington 1997)

Science Learning in Digital Worlds

There is a growing need to recognise the range of digital experiences of young people in out-of-school settings. Young people learn through experience, cognitive conflicts and social interactions and their informal use of new digital spaces represents a new and fertile landscape for these encounters (Gerber et al. 2001). There is only a small body of emerging research on the contribution of young people's recreational use of these digital technologies to their science learning in out-of-school settings (Lyman et al. 2005; Rennie 2007). Here we focus on young people's recreational participation in social networking spaces, video games and gaming communities, and their associated use of multimedia authoring and publishing tools and mobile devices.

Characteristics of Informal Learning in New Digital Spaces

The following themes are prevalent in the emerging literature on informal learning in new digital spaces. Tasks involve self-direction and autonomy and often require peer mentoring. They are collaborative and increasingly mobile in nature, and usually situated in learning networks and communities. They require problem-solving and other inquiry-based processes, where the emphasis is on interaction and creation with new media.

Young people enjoy significant autonomy in these new digital spaces, taking an active role in choosing what, where, how and with whom they proceed, without the time and curriculum constraints of formal school tasks (Lewin 2004). They are strongly self-directed during activities, setting and negotiating their own goals, taking risks (e.g. during games), expressing personally meaningful ideas and testing them on-the-fly (Scanlon et al. 2005; Willett 2007). Experiences are typically learner-initiated, in tune with young people's values and interests (Downes 2006), and with a strong sense of (often collective) ownership. There are especially high levels of ownership of media creations, and there is often a strong remix culture, where young people reuse others' artefacts and expressions (Hsi 2007). Different identities and roles can be adopted in these communal spaces (e.g. roles in games or avatars in social networks). These identities are self-defined and developed online but ultimately interplay with users' views of self, society, gender and race (Hsi 2007). They increasingly use intimate mobile devices enhancing flexible, spontaneous informal learning opportunities (Sharples et al. 2007). Peer mentoring and modelling are distinctive features of these informal e-learning experiences. The emphasis on self-direction means there is a crucial mentoring role to be played by more knowledgeable friends, siblings and other adults (Gerber et al. 2001; Green and Hannon 2007). For example, mentoring occurs in games through peer ratings and feedback given by the game system as well as other players who monitor and mentor progress (Hsi 2007). The tools present in these digital spaces give users an enhanced ability for peer/expert dialogue, asking questions and guidance.

Rich conversations proliferate in these conversational spaces, with users exposed to and expressing wide, differing points of views and experiences. User-friendly and accessible collaboration tools, such as those found in Web2.0 spaces, enable young people to actively participate in tasks, giving them a voice and a strong sense of audience as they explore, share and interact with people and content in authentic ways. Common interests can emerge in these networks and knowledge can be built collaboratively (Lomas et al. 2008; Siemens 2005). Communication is often immediate and multi-modal, by means of shared user-created multimedia artefacts that help form mutual understandings. As well as reading, critiquing and listening, young people typically create, publish and talk around these personally and culturally meaningful artefacts. In this sense, young people become digital bricoleurs (Brown 2000) in these informal learning environments, developing an ability to find something and use it in a new way to build artefacts they value.

Activities often require experiential approaches and inquiry-based strategies can be employed whereby young people formulate and test ideas, raise questions and plan new actions (Brown and Adler 2008; Sefton-Green 2004). Users in online games, for example, often follow an inquiry-based process: making predictions, planning a strategy, testing an outcome and engaging in associated reflective processes. Problem-solving strategies are used, while other online players can provide resources and expertise.

What are Young People Learning in These Digital Playgrounds?

Young people's informal participation in these new digital spaces is altering their social identities, styles of learning, and patterns of communication (Facer et al. 2003; Green and Hannon 2007). Enhanced new literacy skills, creativity, social skills and digital competencies have also been reported (Lewin 2004; Walsh 2007). For example, there is a growing body of literature associating young people's use of Web 2.0, mobile and games-based digital spaces with the development of multimedia literacies. Indeed, these skills have been discussed as 'important for future occupations, civic and artistic purposes' (Warschauer 2007, p. 43), incorporating the ability to interpret, design and create content that makes use of images, photos, video, animation, music, sounds, texts and typography. For instance, in a study of users in Web 2.0 spaces, Charles Crook (2008) found that young people have the opportunity to 'develop confidence in new modes of inquiry and literacy… as well as become literate in digital formats for expression' (p. 4).

Pioneering research in games communities is showing positive links with science literacy development. James Paul Gee (2003) explored the idea of learning how to behave like a scientist while players adopted an identity or playing a character in certain types of games. Other findings include game users' new identity formation, collaboration skills, decision-making, negotiation and resource management skills (Gee 2003), self-monitoring skills, team-based problem-solving and systemic thinking (Squire 2006). More recently, Constance Steinkuehler and Sean Duncan (2008) found that massive multi-player games are worthwhile vehicles of learning, situating informal science literacy in a popular culture context. They specifically investigated games-related forums (e.g. in the massive multi-player online game, *World of Warcraft*) and found valuable informal social dialogue consisting of debates of complex questions where solutions developed by one person were built upon by other participants. Games have also been linked to the development of science discourse skills. For example, the practice of argumentation – as a form of discourse in community settings – is being studied across multiple everyday science contexts (Hsi 2007).

Science Research and Display – Science Fairs

One of the ways in which students engage with science beyond the classroom is through participation in a variety of events that could be broadly labelled as science fairs and science days. They are typically characterised by science research and display.

Unfortunately there is little research to give us the empirical purchase required to draw conclusions about the merits of such events in the science experiences of child and adolescent learners. Views about such events vary. John Craven and Tracey Hogan (2008, p. 680) cite the not unusual example of a science fair where they observed a young girl unsuccessfully but 'earnestly trying to mend' a complicated stack of containers linked by leaking pipes and when asked about the science phenomenon illustrated she explained: 'You see … It's about a dynamic system … and, uh, this water flowing from the top container – here – to the lower container, uh, there. Well, it's flowing … and uh …' At this point the helpful father leapt in to provide an impromptu lecture on the greenhouse effect – something he wrote a paper on 20 years ago. This contrasts with other reports on science fairs (e.g. Ayre 2004, p. 55) which credit the events with generating renewed enthusiasm and commitment as well as energising flagging teachers by engaging them with exciting student projects.

In the early 1960s, Leverne Thelen (1964) and Charles Koelsche (1965) argued that little was known about the influence of science fair participation on the adolescent exhibitors or the characteristics of these participants. Their studies indicated that a majority of students who participated were required to do so as part of their school science program; most students regarded their science fair experiences as positive, winners usually had well-educated parents with proprietary or managerial backgrounds and winners often went on to or expressed an interest in science-related careers and study. Furthermore, it was thought that the flourishing of science fairs and competitions in the 1950s and 1960s would generate an extensive field of research exploring their nature and impact. Similar findings were reported in the 1980s and 1990s (Grote 1995; Czerniak 1996). Yet despite their prominence in the science education landscape for almost 40 years, Czerniak (1996) concluded that 'little research exists on science fairs, and little is known about how these fairs affect student attitudes towards science' (p. 360). Unfortunately, more recently, Senay Yasar and Dale Baker (2003) have observed that most articles about science fairs, science days and student science displays are based on opinion rather than research. As this chapter is written, this remains the case. It is commonplace to find assertions about benefits of such events based on one's experience of them rather than systematic gathering and analysis of evidence. The benefits are typically described in terms of attitudinal or affective outcomes (Barth 2007; Thelen 1964). There seems to be almost universal agreement that these science events promote engagement and enjoyment of science (e.g. Barry and Kanematsu 2006; Grant 2007). There is also some evidence that such involvement in these events may influence students' interest in science careers (e.g. Grant 2007; Koelsche 1965).

Commentaries on science events indicate that their positive outcomes are associated with the opportunity they provide for students: to make choices about what they learn (Aubusson and Griffin 2008; Grant 2007); freedom to pursue matters according to their own interests, abilities and modes of working (Aubusson and Griffin 2008; Grant 2007); and permit students to take control of their investigations (Aubusson and Griffin 2008; Shoring 2000). However, such views need to be tempered by the recognition that commentaries on the outcomes of science events may be skewed, where participants in the events are often those students with significant initial interest in science or provide space for the high achievers to display their work (Yasar and Baker 2003). There is also debate about whether the competition and awards inherent in many science events are beneficial or harmful. Some have suggested that competition may be counterproductive, reducing cooperation and sharing of ideas (Bellipanni and Lilly 1999; Chiappetta and Foots 1984). Others have suggested that academic competition motivates students to perform at their best (Carlisle and Deeter 1989). While stress associated with competitions has been reported (Aubusson and Griffin 2008; Chiappetta and Foots 1984) little is known about the learning or even participation effects associated with competitive events.

There appear to be very few reports that have sought to gather data about what students learn in research and display events. In a quasi-experimental study of over 300 students, Yasar and Baker (2003) investigated the potential relationship between science fair participation and students' knowledge of scientific method and their attitudes to science. However, the pre/post-test data revealed no statistical differences between experimental and control groups on these measures. These findings contrast with anecdotal reports on the contribution of science fairs to student learning and emphasise the need for further research to explore the argued impact of science fairs, notably, the effects of science fairs on students' understanding of scientific, systematic inquiry.

In a recent study of five schools with groups of students participating in a science research and display event, Aubusson and Griffin (2008) investigated learning outcomes and factors hindering and promoting the success of the process. They interviewed over 50 students and 16 teachers as well as collecting data during student display days. The open-ended questioning revealed that the types of learning from the process were not restricted to scientific method or attitudes to science but were related to generic learning outcomes. For example, students claimed that they learned: science concepts, propositions and applications; presentation skills; to work as a team; how to learn from each other; to ask and refine questions; and project management skills as well as how to do research. Teachers made similar claims. Thus it seems that the science research and display events serve far broader purposes than those typically attributed. Furthermore, both teachers and students stressed that they were more motivated and engaged than in regular science classes. In an interview, one student outlined key features underpinning the experience they had in the process:

> We decided we had control over our own learning which motivates people more if they're going to go and find out what they want to find out about instead of the teacher saying find out about this and that. Partly the actual building of the presentation and partly just seeing people interested in what you have created - sharing knowledge together and combining the knowledge, and we do learn what others know so we can also contribute what we know as well. A way of learning that we haven't done before, because we had to do everything ourselves, the questions – we learnt how to learn as well as learning what we learnt. (Aubusson and Griffin 2008, p. 23)

Features contributing to the perceived success of the science days include: giving student choice about what they learnt about, permitting considerable autonomy and control over how they went about their learning, availability of support and resources; establishing a clear purpose and goal/product, and collaboration. It seems striking that the features that are claimed to have positive motivational effects may be most evident in the atypical science events rather than being integral to mainstream science teaching. It begs the question: What features of such atypical science experiences might be harnessed in regular science classes?

Implications for School Science

Science learning beyond the classroom is associated with high levels of motivation underpinned by attributes of choice about what one wants to find out, a clear sense of purpose and some control over how one goes about finding out. Learning processes are typically derived from exploration and inquiry into a problem, question or a specific contextual phenomenon – rather than a generalised principle. Associated learning opportunities may help young people develop new ways of thinking, interpreting and engaging in scientific inquiry. By contrast, when they come to school they may be limited by less sophisticated resources, constrained by lock-step curricula and restrictive teaching strategies. Hence, there is a growing incongruence between students' informal and formal learning environments (Griffin and Aubusson 2007). There is tension between everyday learning and teachers' views of learning (Hsi 2007). This accentuates the need for school science to acknowledge the potential of exploiting natural learning processes that operate when students occupy settings beyond the classroom. This requires a reframing of what counts as legitimate learning in school science.

School science needs to take more account of young people's out-of-school science learning experiences and develop greater consistency to synthesise learning across formal and informal domains. This could involve design and mediation of student-initiated project-based tasks utilising new literacies, collaboration and creativity that resonate with students' experiences. Teachers have a key role to play in these collaborative project-based science tasks, in modelling and mentoring to support self-directed processes, particularly at the crucial initial stages of projects, and especially among students with learning support needs (Warschauer 2007). Indeed, young people need teachers' help to understand the broader context of their school science experiences. They need support for 'developing skills for appraising evidence, recognising social and other influences and implications of decision-making and research' (Osborne and Henessy 2003, p. 41).

Science learning tasks need to enable rich conversations that extend beyond formal school settings. For example, Angela McFarlane and Silvestra Sakellariou (2002) advocate science learners using the Internet to produce and publish their own critique and analyses of important topics such as food safety, genetic engineering, nuclear power and environmental pollution. They further advocate discussing and exchanging ideas with peers in learning communities for '(i)n this way, school pupils can expose their interpretations of science to peer review and truly experience the way research proceeds in an authentic fashion' (p. 230). Collaboration and conversation among peers, sharing with and questioning of experts and teachers encourage learning from each other. Extending these conversations through creative display to peers and parents should invite dialogue and contribute to peer review and the scrutiny of ideas.

A central theme in all the studies in this chapter is autonomy, which could suggest a free-for-all anarchy leaving young learners to their own devices in school science. Such a position is fundamentally inconsistent with the studies considered here. This is perhaps well illustrated by the critical part played by orientation where the teacher lays the foundations for a learning pathway using activities to stimulate curiosity, and initiate explorations that lead to more systematic inquiry. It seems inherently paradoxical but autonomy and independent learning require high support if learners are to flourish in intellectually challenging science learning environments (Aubusson and Griffin 2008). Warschauer (2007) has elaborated on this in what he calls the ‘how paradox’ (p. 44). That is, for students to become autonomous learners in informal environments they require extensive mentoring and support from their teachers in school environments. Hence, what is required is not anarchy but a rebalancing and shift of emphasis that entwines school science with out-of-school science learning experiences and processes.

There needs to be an understanding of what constitutes informal learning in science-related contexts, where new boundaries have emerged and how these boundaries can be broken down. The consideration of learning in settings such as museums and zoos; in digital spaces such as Web 2.0 and gaming sites; and through science research and display events, such as science fairs has indicated that there is no utopia. These environments are no doubt as capable of failing young learners as schools are. However, when they succeed, a set of characteristics of participation becomes evident including: autonomy, interactions with friends and artifacts; peer, parental or teachers’ support; creative display in social spaces. These generate high levels of engagement and enjoyment with patterns of deep involvement and commitment akin to the concept of ‘flow’, where people become immersed, absorbed by and experience intrinsic reward from their activity (Csikszentmihalyi 1997, p. 956). These features do not sit well with school science, which involves the acquisition of a multitude of prescribed science content, concepts and propositions as abstractions. However they are consistent with school science involving deep understanding of relevant contexts. This provides a platform for building generic learning capabilities such as new literacies, project management, team work and communication.

Learning within and beyond the classroom is imperfect. Here we have consciously focused on features of learning in settings beyond the classroom that are beneficial and that have potential applications in school science. The intention has not been to imply that places such as museums, digital spaces or science fairs have impeccable credentials as learning environments. Nevertheless, they have much to offer science education research if we are to consider a school science that is deep rather than broad; engaging not disengaging; more collaborative than competitive; about building capability rather than acquiring information; and more relevant. The studies we have considered identify characteristics that might be appropriated in school science in order to embrace significant contemporary issues and problems that resonate with young people together with an emphasis on curiosity driven exploration, inquiry and knowledge exchange.

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Chapter 75
Science Stories on Television

Koshi Dhingra

Science stories are constructed in a wide variety of contexts all the time. Textbooks and novels, oral accounts of observed phenomena at conferences, in the kitchen, garden, or the playground, and so forth all deliver edited accounts of the natural world to various audiences. A story, as discussed by Joan Solomon (2002), provides its own reality to listeners or viewers and allows its readers, viewers, or listeners to readily empathize with its characters, thus establishing a ready rapport with them. In the current global context, where the web of science communication contexts is increasingly complex and irregular, involving emails, mass media, scientific journals, textbooks, and so forth with decreasing times taken in the communication process and with no clear focal point, one emerging question is: What effects does such a web have on the nature of science stories that are constructed?

A perspective of science as a collection of stories communicated through a diverse collection of media raises a host of questions. What makes a story a science one as opposed to a different type of story? What activities lend themselves to generation of science stories? What factors shape the editing process, whether it is done at an individual or collective level? How do people, in their everyday lives, make meaning of all the science stories they receive from the various sources and media they interact with? How do contradicting science stories interact with each other in various cultural contexts? In this chapter, I raise these and other questions about the science stories that are constructed on television, a medium that is extremely proficient at telling stories through pictures and words to very wide audiences across the globe. It is a medium that has been evolving since it was introduced to society about 75 years ago. Television functions as a storyteller and as a significant public space for the presentation and exchange of ideas housed in the stories that it tells. It is,

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therefore, an important learning tool. Learning, in any environment and using any medium, involves a dynamic set of interactions, activities, and shifting identities-in-practice. As such, learning about the learning of television viewers is complex. Third, television and other mass media, in their role as public fora, play a crucial role in public discourse on new science and local, community-based science issues. With greater ease in merging the World Wide Web and television and with greater abilities in producing programs for targeted audiences, viewers may be able to use television for a range of functions, from partially customized education to participation in democratic decision-making.

Television represents a significant public space. More Americans select television as their primary source of science and technology information than any other medium (National Science Board 2008). International Telecommunications Union (2009) estimates show that three quarters of households now own a television set and over a quarter of people globally – some 1.9 billion – now have access to a computer at home. This points to the huge potential for converged devices, as the mobile phone, television, and Internet worlds collide. However, television's potential has yet to be harnessed to the ends of the key goals of science education and in synch with other science communicators. To what extent and in what ways can science communicators working in different contexts, such as school, museums and other informal learning centers, television, and other mass communicators, work to move toward the key goals of science education? What processes are at play when the culture of science is recorded on film and televised to the myriad publics which constitute society? What effects do different types of televised records have and what potential effects could they have? What relationships exist between filmmakers, science experts, other science practitioners, and other social actors?

Science on television, whether in the form of news, drama, documentary, or children's educational shows, frequently represents the product of intersections between public and specialist discourse. Health, science, and technology practitioners frequently consult on television programs, and real and depicted science and technology practitioners are abundant on many television programs, providing connections to specialist frameworks. Researchers, science communicators, experts (whether scientist, policymaker, or politician) who use television as a mode of communication, educators, and television practitioners in the industry all need to see science communication that uses the medium of television through the lens of "cross-talk." We need to see television as the venue for multiple, multidirectional interactions between different groups of citizens all engaged in science in their lived experiences. The result would be the generation of multiple interpretations by viewers and increasing levels of dialogue between individuals and groups.

I define science as an umbrella term for a wide range of largely social activities. Examples include research done in prestigious research centers, children's investigative play with sand or water, and a gardener's practices when tending to his blooms. The communication of the nature of knowledge and of the processes of knowledge production – through classroom talk, textbooks, newspapers, television programs, and so forth – is an influential communication which shapes individuals' relationships with scientific activity and new science stories. A new contract between science and society which will ensure that scientific knowledge is socially robust needs to be put in place. This new contract needs to focus on knowledge production that is both transparent and participative. The media play a key role in the design of this new contract since they constitute much of the public space in which science dialogues with the public, as proposed by Michael Gibbons (1999). Both societal and scientific problems are framed, and their solutions are negotiated in this public space. Thus, how scientific knowledge comes to be known and how it is used are key aspects of the science stories that should be told on television and elsewhere. In this chapter, I will outline the types of science stories that tend to be televised.

Natures of Science Constructed on Television

The natures of science constructed by television programs largely fall in four different genres: stories connecting to citizen science (largely news stories), documentary, children's educational programming, and dramatic series. Science on television ranges from being presented as a collection of factoids to comprising a dynamic set of tentative knowledge claims that are open to question. There seems to be a tension between a desire to screen and to view scientific certainty and achievement and the inherence of uncertainty in science in action. Similarly, there exists a tension between the abstractness of much of scientific knowledge and television as a visual medium, resulting in an emphasis on the life, medical, astronomical, and earth sciences (all of which are associated with easily available and powerful images) and an underemphasis on physical and chemical sciences (less associated with such images). Relevance was seen as the key factor that determined newsworthiness of a science item in the news, as reported by James Bennett (1999). This highlights the need for the construction of relevance in the presentation of the science story. It seems, in short, that we are still far away from a portrayal of diverse science and technology. Emphasis on science as a human process would lead to the construction of a strong narrative arc and would allow for greater presentation of science stories dealing with physics and chemistry.

Science practitioners on television similarly range from being one-dimensional characters to multifaceted individuals who work in fields that involve scientific processes and knowledges. Character selection is an important dimension of the nature of the science story that is constructed. I reported in an earlier study (1999) that the relationships formed by teenage viewers with the characters on screen were an important factor in determining the nature of students' reactions to the messages about science and scientists housed in a range of television genres. In this same study, quantitative analysis of gender and ethnicity of all characters portrayed as science and technology practitioners on screen found that women and people of color were significantly underrepresented. It seems, in short, that we are still far away from a portrayal of diverse science and technology.

Stories Connecting to Citizen Science

As citizens deliberate on such issues as children's vaccinations, disease treatments, gene modified foods, pollution in local water sources, global warming, ozone depletion, nuclear energy, oil drilling, suggests Alan Irwin (1995), it is important to acknowledge that citizen science is a significant body of understandings that is frequently local in context and that is influenced by a range of science communication modes, including television. Here, I survey some ways in which citizen thinking is represented and modeled on television. Television and other mass media in their role of public forum play a crucial role in public discourse on new science and local, community-based science issues both of which tend frequently to be associated with risk and uncertainty. Risk and uncertainty are at the heart of many of the science-related decisions that citizens need to make for themselves, for their communities, and as voters for their state.

Although it does not explicitly focus on science, a content analysis of a large number of television news stories in the UK and the USA conducted by Justin Lewis, Karin Wahl-Jorgenson, and Sanna Inthorn (2004) revealed that ordinary citizens were depicted as being almost childlike, with moods and experiences but not shown deliberating on issues. Opinion polls featured in the US media ran significantly in favor of conservative opinions, with no mixed opinions being depicted at all, contradicting other studies cited which indicate that US public opinion does not reflect this same bias. The British TV news media were found to be less inclined to show opinions of any political bias. Examples of mixed opinion were found to be extremely rare in both the UK and the USA. The researchers conclude that citizens were, for the most part, shown as "passive observers of the world" who, while they are shown to have "fears, impressions and desires…do not, apparently, have much to say about what should be done about healthcare, education, the environment, crime, terrorism, economic policy, taxes and public spending, war, peace or any other subject in the public sphere" (p. 163). The researchers note that the most profound obstacle to showing active citizens on television news may be the structure of political reporting by which the focus is on what politicians do as opposed to what people want them to do. This may well be true of reporting on science-related issues: the focus may be on what the experts/scientists do and say as opposed to including emphasis on social implications and citizen deliberations.

Similarly, Dominique Brossard and James Shanahan were interested in looking at how television's representations of science fostered, if at all, public deliberation on and participation in science-related policy issues, in particular, in the case of agricultural biotechnology (2003). Overall, media did foster informed participation among citizens through both direct and indirect effects. Individuals using more heterogeneous sources were more positive toward public participation in science-related decision-making. In contrast, individuals with greatest levels of scientific knowledge, in general the more educated individuals, tended to have the greatest levels of unconditional trust in science and the most authoritarian attitudes about science-related issues. In other words these individuals, perhaps owing to cultural conditioning presenting science as a field in which only scientists could make informed decisions, did not feel that the public at large should play a role in scientific decision-making. The researchers note that this conclusion is in striking contrast to previous studies showing that more educated people tend to be more politically engaged than others. This study points to interesting questions about the educational system's portrayal of the relationship between science, scientists, and public opinion. This is similar to results from a different study reported by Dietram Scheufele (2002), in which he found that individuals who watched television news and also engaged in political discussions with others tended to be more politically active than those who did not engage in such discussions.

The complexity of the relationship between source materials and media coverage is worth considering when we try to understand messages that are communicated through the telling of a story. In Richard Holliman's study of the newspaper and television news coverage of cloning (2004), results pointed to the notion that, scientists, politicians, officials, and other professionals and experts from the UK, other European countries, and the USA were all significant sources of cloning news in the sample. In addition, the story of Dolly's cloning was facilitated by active promotion on the part of the scientific institutes involved in the science leading to continued coverage. The fact that Dolly, the sheep was not only a science story but also a political and ethical controversy was also felt to make this a big science story with extensive coverage on both television and the newspapers. It seems clear that media coverage is the product of a social negotiation by a wide range of actors who mediate information within a particular set of circumstances, and for specific reasons. Further, Holliman noted that respondents tended not to remember the details of the science news story but did internalize the big picture ideas from media messages. Also, personal experience played a big role in determining the nature and degree to which respondents interpreted and contextualized media reporting of science. There was a range of responses to the news stories, ranging from highly motivated respondents who were very interested in seeking out additional information and applying the science stories to their own contexts to individuals who remained ambivalent or apathetic. This highlights the idea that the public chooses whether or not to make meaning of the science presented on television or by other media sources based upon a wide variety of factors including social context, education, alternative sources of information, preexisting attitudes, beliefs, and experience.

These studies point to the complexity of effects at play when we look at the effects of television-mediated science on citizen expertise and public participation in decision-making around science-related issues. The role of citizen expertise and its relationship with media presentations of science are involved in a complex set of interactions all making for dynamic and variable levels and types of scientific citizenship amongst the public. Television has the capacity to encourage greater awareness of opposing political views. However, Dianna Mutz posits that the increasingly popular format of "in-your-face" TV, with its uncivil tone and intense camera close-ups, causes audiences to react more emotionally and regard those opposing views as less legitimate than they would otherwise (2007). Further study needs to be done on how conversations about science in the political news are handled and how viewers respond to the nature of the coverage.

Children's Educational Programming

This is a mixed category of programs, containing magazine format shows as well as a wide range of other formats. A look at the structure of the program using such criteria as those described by Boiarsky et al. (1999) can be informative. They analyzed a variety of formal features used in approximately a dozen episodes each of five different children's science programs in the USA. Formal features address the non-content elements of a program, such as cuts, wipes, fades, dissolves, zooms, and sound effects, which are known to influence children's attention to the television program, and hence, which affect learning from the program. In this study, the sample of children's science education program was analyzed for number of cuts, wipes, fades/dissolves, sound effects, and also for content pace. The data collected pointed to the fact that while the programs included numerous attention-getting features, they contained few formal features that would encourage thoughtful processing of content such as fades/dissolves and wipes. The programs also changed topics very rapidly, although the researchers point to a need for further study on the effects of rapid topic change but with low absolute volume of information (in other words, a lot of repetition) versus rapid topic change with large volume of information dealt with in the program (i.e., little repetition). The researchers suggest that the high number of attention-gaining formal features and the rapid pace of the programs may work against one another resulting in little learning on the part of the viewers. They note that this prediction depends upon the differential effects of topic change and information volume on learning. They suggest that owing to the high levels of competition on television, science education programs may be adopting more entertainment characteristics in an effort to attract larger audiences. They point to a need for further study on the effects on learning of children's science programming as well as for more content analyses of such programs.

In a content analysis of the characters in the same four children's science education programs, Marilee Long, Greg Boiarsky, and Greg Thayer (2001) found that counter-stereotypical images of scientists and people interested in science were represented. Both males and females were equally likely to be scientists and spent the same amount of time on air in each episode. Status, as evinced by clothing and character knowledge, did not differ by gender or ethnicity. However, the number of male characters outnumbered the number of female characters and males on the programs were more likely to be adults whilst females were equally likely to be adults or youths. Further, visiting characters were more likely to be adult male Caucasians. In all cases, minorities were less likely to be labeled as scientists, spent significantly less time on screen than did Caucasian scientists, and there were significantly fewer minority characters as compared with Caucasian characters. It seems that although progress has been made in the area of reducing gender biases in children's science education programs, much more needs to be done when it comes to representation of minorities as scientists. In addition, all the scientist characters on these programs constituted only 16% of the total character population. Thus, if viewers are affected by sheer numbers, it is highly likely that they would overlook the scientist roles in these programs. This study points to a need to consider choices of characters carefully, with regard to age, gender, and ethnicity. The researchers suggest several areas for study including examination of whether there needs to be overrepresentation of females and minorities in science education programs, relative to their proportions in the US census. They also suggest looking at whether viewers pay more attention to main or visitor characters; if they pay more attention to main characters, then minorities need to have more such roles and these characters need good amounts of time on screen.

Although not billed explicitly as a children's science program, *Blue's Clues*, a preschool television series on Nickelodeon, with its emphasis on problem-solving and exploration for clues demonstrates the inquiry process consistently, with a few episodes focusing more explicitly on science content (e.g., planets, insects, senses). In a qualitative study I reported with Dhingra et al. (2001), we took a closer look at the production of a single, science-related episode of *Blue's Clues*. We found that four major kinds of initiatives or strategies were used to build in high interactivity levels in combination with longer than average periods of wait-time, designed to elicit responses from viewers in response to questions posed by the characters. These were: viewers were repeatedly asked to participate; questions were directed to the viewer; suggestions were made to viewers of strategies they could use to problem-solve; preschoolers' voice-over responses to questions. A 2 year, longitudinal study of the effects of *Blue's Clues*, conducted by Jennings Bryant and others, found that regular viewing contributed substantially to preschoolers' visual attention to the program, their perceptions of being able to help Steve solve problems, their information acquisition, and their problem-solving abilities and flexible-thinking skills (1999). *Blue's Clues* was telecast 5 days a week with the same episode being presented on 5 consecutive days – an unusual telecast strategy that was based upon child development theory and practice that states that children, especially the youngest children, learn and master skills through repetition. Anderson et al. (2000); Bryant et al. (1999); Crawley et al. (1999) looked at the effects of this telecast strategy and found that repeated experience with an episode bolstered children's participation with both *Blue's Clues* as well as with a different program that the children had never seen before.

Entertainment Education Stories

The entertainment-education (EE) strategy is a specific type of storytelling which involves incorporating an educational message into popular entertainment content in order to raise awareness, increase knowledge, create favorable attitudes, and ultimately motivate people to take socially responsible action in their own lives. The Center for Disease Control (CDC) in the USA established a formal entertainment-education (EE) program in 1996 with the goal of becoming a vital component of an integrated public health strategy by, among other things, providing accurate and timely information about public health to the entertainment industries (Center for Disease Center 2000). An important landmark in entertainment-education in the USA was the

Harvard Alcohol Project's National Designated Driver Campaign, developed by the Harvard School of Public Health's Center for Health Communication, launched in 1987, which tried to change social norms with regard to drinking and driving. Through meetings with more than 160 producers, writers and media executives, the Project was successful in planting the designated driver concept in more than 80 television episodes and promoting the concept through network-sponsored public service advertisements, reaching an estimated 45 million viewers. Survey data showed significant increases in awareness of and compliance with the designated driver concept during the period in which the Project occurred. In 1991, the term "designated driver" was included in the Random House Webster's College Dictionary.

What, if any, effects do entertainment-education television programs have on the viewing public? A body of research is emerging that assesses the impact of entertainment education as a strategy for reaching the public about health issues (Kaiser Family Foundation 2004). A survey of prime-time TV viewers conducted by the Center for Disease Control in 2000 found among other positive results that 48% of regular viewers who heard about a health issue on a prime-time TV show say they took one or more actions: told someone about the storyline (42%), told someone to do something or did something themselves, such as use a condom or exercise more (16%), visited a clinic (9%), or called a clinic, health-care facility or hotline for more information (5%).

EE strategies have also been successful in international contexts. For example, Soul City in South Africa achieved high audience ratings and commercial success while demonstrating innovative initiatives in improving public health in some African countries and in South Asia, as reported by Arvind Singhal (2004). Interestingly, Soul City is mostly a research and management organization which coordinates the activities of its various corporate, government, media, and donor partners. They own the media product that is produced and commission health communication materials from professionals and ensure high quality through research. Further, the reach of Soul City extends beyond South Africa, thus multiplying its impact. In partnership with UNICEF, Soul City Materials are distributed in six neighboring African countries and more African countries have requested Soul City materials for local use. Other successful EE efforts include *Hum Log* in India, *Tushauriane* in Kenya, and *Twende na Wakati* in Tanzania. Messages in such widely viewed programs can have significant effects to the extent of helping to create needed infrastructure. For example, Hum Log encouraged the signing of eye-donation cards in India, when, in 1985, an episode showed a police officer who needed an operation to restore his eyesight.

Documentary Stories

In the UK and USA, since the late 1960s, documentary producers hoped that their work would help "citizens to better navigate the modern world," according to filmmaker John Palfreman (2002, p. 34). Palfreman was a documentary filmmaker who moved to work at a public affairs television program in which the onus was on presenting multiple perspectives on topical issues including silicone breast implants, climate change, genetically modified food, powerline electromagnetic fields, nuclear energy, etc. He now recognizes that although having powerful visuals and excellent scientist-communicators who can connect to audiences are valuable pluses in making a science documentary, what is more important is reporting on complex and fascinating current questions in science and society. This would be in keeping with the original mission of the pioneers of science documentary production three decades ago and would serve citizen viewers well in making sense of science. He critiques most contemporary documentaries produced in the UK and the USA as having "settled instead for a limited set of bankable topics that would bring in viewers" (p. 33). He notes that the combined demands of ratings and long shelf life are the key reasons that producers have moved away from journalistic films in which new science is explored and in which "un-sexy but important science" is presented. Currently, according to Palfreman, a handful of genres of science documentaries exist: archaeology genre, dealing with expeditions, lost treasures, mummies, dinosaur bones, etc.; forces of nature genre, dealing with volcanoes, tornadoes, mountains, sharks, etc.; modern history genre, exploring certain mysteries left over from past wars such as missing submarines of Hitler's Third Reich; and cool gadgets genre such as racing cars and helicopters. Although many excellent films are produced, they have less and less connection to the real-life activity of research laboratories and science in action. Current strategies to get programs produced and on air include coproduction, by which the investment is shared and producing different, culturally acceptable versions of a program so that it appeals to a range of different markets. Even in the presence of a wide range of outlets for science stories on television (Discovery, the Learning Channel, BBC, cable and satellite channels, and an enormous number of pay TV channels), there is an increasing streamlining of content to cater to international tastes. There is a growing international market for science programs even if, to quote a broadcast magazine in the UK, commissioning editors are on the lookout for what sells which tends to be "sex, space, weather, disasters, dinosaurs, and freaky people." Thus, while science may be seeming to gain airtime on television internationally, we seem to be, in fact, moving further away from Irwin's notions of local knowledges being supported in local contexts.

How and What We Learn From Science on Television

Learning via television may be a unique cognitive phenomenon. The nature and effectiveness of learning via television depends upon the construct of the program, as well as a host of other factors. These include viewer characteristics such as age, gender, socioeconomic level, cognitive maturity and family background, context of viewing, purpose of viewing, alternate information sources used. In addition, van Evra comments that viewing activity includes factors such as amount of viewing, cognitive processing (attention, mental effort invested, comprehension, and linguistic processing), program preferences, and perceived realism van Evra (1998). Student participants in my study Koshi Dhingra (1999) varied widely in their responses to televised science, indicating that they bring rich and differentiated schema to the interpretation of what they see. Clearly, simple comparisons of programs and viewers would fail to address the complexity of all that is involved in television science and its effects. In order to explore the construction of science by television, it is essential to study not only the types of content that students perceive as being scientific, but also the students' background variables to see how they influence their viewing experiences.

Finally, much more than scientific meaning is communicated in science education discourse – on television as well as in classrooms. Companion meanings are communicated which can contribute significantly to what and how the viewers learn. A view of science, nature, technology, a view of race and gender (e.g., who are the experts?) as well as a view of the relationship between humans, nature, and technology is also learned. As such, efforts made to understand the effects of science on television must be sensitive to the multiplicity of factors affecting program development and viewer interpretation.

Science communication, whether in school or in other settings, would be serving the public best if opportunities for question and critique were highlighted and built in so that the communication moves from being a one-way flow of information to a dialogue, and perhaps even a conversation, about the multiple factors and perspectives usually at play in relation to a science-related concept or issue. Television, on its own, and in concert with other mediating experiences including home and family, other media, and classroom experiences is well positioned in the public space and is, therefore, an extremely significant science communicator. The effectiveness of the quality of television, with regard to furthering the goal of sociopolitical action and scientific citizenship, as discussed earlier in this review, depends upon the ways in which the following actors and the relationships between them are constructed on television: science experts, lay experts, and other citizens. This, in turn, constructs science as a body of knowledge, and the relationships between science and society.

Finally, the following are some questions that address the need for television practitioners and science experts to partner with educators in the collective goal of producing socially relevant stories relating to science which also help viewers appreciate their role as actors involved in current science-related issues. How can science experts be encouraged to view communication with the public as an important dimension of the scientific process, to the end of the production of socially robust knowledge, as discussed earlier in this review? How can research guide the production of televised science in a more systematic way? How can television be used (in concert with other tools and media) to expand public participation in new science? With the current move toward more cable networks providing niche programming for a preselected range of viewer interests (such as Discovery channel, cable news channels, History channel, and so forth) and with local public television networks funding broadcasts for a particular geographic area, how can television be used to mediate local, community-relevant science-related knowledges?

Clearly, at this point, there are many more questions about televised science, its relationships with society, and its future than there are answers. This points to the need for a significant amount of study in this area and also for the need for science educators to identify themselves, not only as working within school contexts, but as a group working within a larger cultural context and in partnership with a wide range of other science communicators.

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Chapter 76
Museum–University Partnerships for Preservice Science Education

Preeti Gupta and Jennifer D. Adams

In this chapter, we demonstrate the value of informal science institutions to serve as partners to university-based teacher preparation program by describing programs in three international contexts. Our standpoint is shaped by our experiences as museum educators, teacher educators, and education researchers. The first author (Preeti) developed an interest in science teaching particularly because of her experiences as a student working as floor staff at the New York Hall of Science. The second author (Jennifer) has had experience teaching in multiple contexts – high school classroom, in a museum setting, and in a teacher education program. We believe that learning to teach is a practical activity and is shaped by sociocultural, historical, and political processes. Through our personal experiences and research, we have learned that active engagement and participation in low-stakes teaching activities within informal science institutions mediates the development of practices, understandings, and local theory about teaching and learning. Both of us firmly believe that the patterns that emerged across the three programs described in this chapter are important to understand because traditional university-based teacher preparation programs often lack the time and structure to support teachers in developing their epistemologies and ontologies toward teaching and learning, especially to diverse learners. In some cases, traditional programs continue to divorce theory from practice. Partnerships with informal science institutions could strengthen teacher education programs and provide them with an invaluable resource where theories about teaching and learning could be merged with practice in a novel, resource-rich context.

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The Potential of University–ISI Partnerships

Informal Science Institutions (ISIs) are spaces designed for learning about science and the natural world. Existing within the larger context of museums,[1] science centers, nature centers, natural history museums, zoos, aquaria, botanical garden or arboreta, are free-choice settings with the overall goal of exciting, engaging, and educating the public in science and technology. Although many ISIs include education as a central part of their mission statements, the potential role that ISIs could play in teacher education has yet to be fully realized. However, there is growing evidence that suggests that university–ISI partnerships for teacher education could provide a rich context for preservice teachers to learn about and practice teaching science.

Sally Middlebrooks (1999) learned that both the ISI and college faculty felt that such partnerships allowed preservice teachers to practice teaching with demographically different audiences, observe different styles of teaching, and make connections with ISI staff as mentors both during their preservice program and later, during their in-service experiences. Almost a decade later, David Anderson, Bethany Lawson, and Jolie Mayer-Smith (2006) investigated how the epistemologies and pedagogies of teaching and learning of preservice biology teachers enrolled at the University of British Columbia were influenced by a 3-week practicum in an aquarium setting. Preservice teachers had opportunities to lead workshops, facilitate interactions between the visitors and exhibits, and develop aquarium-based curricula. They learned that in such practicum experiences, preservice teachers understood that valuable teaching and learning can happen outside of the classroom, appreciated the value of hands-on learning, and learned to recognize and react to "teachable moments." They also gained practical skills such as, teaching diverse learners, doing collaborative group work, and classroom management skills. These patterns in the data set the groundwork for the University of British Columbia's current project where they expand the number and type of institutions that preservice teachers can select for their practicum experience.

Along with the program at the University of British Columbia, in this chapter we discuss patterns emerging across similar partnerships in two other international contexts. In these three projects, preservice teachers work as staff in the ISI as a way to practice the art of teaching. We describe how this model is enacted in these international settings, unique to their own requirements and resources. Although the different partnerships present different approaches to the university–museum partnership and the roles of preservice teachers as staff, certain similarities emerge in the findings for each of the projects that have implications for the prospective role of ISIs as

[1] International Council of Museums' definition of "museum": A nonprofit-making, permanent institution in the service of society and its development, and open to the public which acquires, conserves, researches, communicates, and exhibits, for the purposes of study, education, and enjoyment, material evidence of people and their environment (1989).

partners to universities/colleges for teacher preparation. We begin by presenting an argument for the need for such partnerships and why ISIs provide fertile contexts for preservice science teacher education.

The Need for ISI–University Partnerships

According to the National Association for the Council of Teacher Accreditation (NCATE) in the USA, a highly qualified teacher is one who has mastered and is able to demonstrate qualities of strong knowledge, skills, and dispositions. In fact, NCATE requires that when colleges and universities apply for accreditation, evidence of developing and measuring knowledge, skills, and dispositions is present and especially visible in their conceptual framework. However, in spite of these seemingly stringent requirements, many people are graduating from programs without having opportunities to develop their skills and dispositions in practice and especially in working with diverse students (Villegas and Lucas 2002). Linda Darling-Hammond, Karen Hammerness, Pamela Grossman, Frances Rust, and Lee Shulman (2005) argue that many teacher preparation programs are criticized for being "overly theoretical and lacking connections to practice" (p. 392). In most cases, it is assumed that clinical experiences involving fieldwork and student teaching allow teacher candidates to be exposed to students and develop their dispositions toward teaching. They also claim that, too often, clinical practice is divorced from theory because institutions are not able to create coherent links between the coursework and student teaching experiences. In other words, preservice teachers do not have the opportunity to develop spielraum, or the ability to maneuver in multiple ways to engage diverse learners. Wolff Michael Roth, Daniel Lawless, and Domenico Masciotra (2001) describe spielraum as developing practices that are anticipatory, timely, and appropriate to given teaching situations. Then, "…the teacher's readiness for action allows an unfolding of a realm of appropriate possibilities within the immediacy of the student-teacher transaction. Second, this realm of possibilities, in turn, allows the teacher a point of entry to unfold the reality of the students' understanding" (p. 186). Developing spielraum is developing fluency in science teaching; that is, where "discrete actions are coordinated and interwoven with practices to constitute a seamless whole as participants appropriate resources" (Tobin 2005, p. 28). In a carefully constructed university–museum partnership, teachers have opportunities to connect their clinical experiences to the theoretical foundations that they receive during coursework; they can observe, practice, and reflect on theory-in-action. Additionally, they learn how to informally assess learning, which could complement the formal measures of student data that are often stressed in formal teaching environments (both in their traditional coursework and in the formal classroom), all factors important in developing spielraum.

Informal Science Institution Facilitators

Facilitators work in ISIs and create a scaffold between the visitors and exhibits. Paola Rodari and Maria Xanthoudaki (2005) state that by engaging various audiences (families and school groups) in conversations about the complex topics presented in exhibits, facilitators serve as human interfaces between the exhibit's intended purposes and the visitors' interests. Miha Kos (2005) claims they are the direct link between the visitor and the exhibits. Across science centers internationally, these facilitators (referred to by different titles at different sites) have varied levels of responsibility. Some of the tasks of museum facilitators include (but are not limited to) interacting with visitors in the exhibit galleries, conducting demonstrations, facilitating lab activities, working with object carts, leading workshops, and developing activities for school-group use.

In order to prepare floor facilitators for active engagement with diverse visitors, museums put significant amounts of time and effort into training. Current discussions on facilitator training have focused on the need to model diverse teaching approaches, shifting them from transmitters of information to guides who assist visitors with inquiry experiences. The DOTIK[2] (2007) study finds that facilitator training and mentoring is critical to the facilitator's science communication skills, comfort with public speaking, and ability to engage with diverse audiences. These skills are a solid foundation for anyone who might consider teaching as a career. As former ISI educators, we are proof that experiences as staff in such settings can alter one's trajectory in life, develop dispositions toward teaching, and build a teaching identity. We argue that ISIs are potentially effective sites for teacher education as they allow aspiring teachers to practice teaching through actively engaging diverse audiences in science activities. With access to a variety of science-rich experiences, ISIs are rich learning laboratories for future teachers.

Preservice Teacher Education in Museums: Practice and Potential

Kenneth Tobin and Wolff-Michael Roth (2006) theorize that learning to teach is a practical activity. In order to learn how to teach, one has to actively engage in the activity of teaching. Learning can happen across different contexts (Bruner 1996); thus, the learning that happens in one context can influence learning and action that happens in another context. Relating this to learning to teach, knowledge, skills, and dispositions learned and developed while teaching in a museum context can influence one's ability to teach in formal school contexts. In-service teachers who participated

[2]DOTIK was a 2-year funded project from the European commission aimed at developing and testing methodologies for training museum educators (www.dotik.eu).

in 60 h of museum-based professional development were able to introduce practices in their classroom that were more reflective of the museum's inquiry-based and object-based contexts (Adams 2007). Therefore, for preservice teachers, who are in the process of developing an emerging teaching practice, having actual teaching experiences in an ISI context could have the potential of developing skills and dispositions that are more reflective of a free-choice learning environment.

April Luehmann (2007) reminds us that one of the challenges that we face in preservice teacher education is the lack of opportunities to be successful at teaching in low-stakes environments. ISIs are low-stakes education environments in that they lack formal assessments of learning and visitors often come for a novel (fun, entertaining) experience. This context presents an increased likelihood of successful teaching interactions with visitors for ISI facilitators. When ISI facilitators feel successful at interactions with visitors, they try it again and again, each time learning how to adjust their interactions to meet the needs of changing visitors and therefore developing spielraum.

In the following sections, we provide an overview of the three partnerships, including the central museum teaching activities, description of the patterns emerging from teaching in an ISI setting, allowing us to make assertions about the role of museum-based practice in preservice teacher education. Each of the partnerships continues to exist and engage in ongoing data collection, including interviews, surveys, focus groups, regular journals or logs, and observations. Our analysis is based on research data and evaluation reports from each of the partnerships. Stakeholders in all three partnerships have reviewed the descriptions and claims presented here to ensure their accuracy.

Collaboration for Leadership in Urban Science Teaching Evaluation and Research

The Collaboration for Leadership in Urban Science Teaching Evaluation and Research (hereafter referred to as the New York program) is an NSF-funded research project awarded to the New York Hall of Science (NYHS) in collaboration with the City College of New York, a 4-year college that is part of the City University of New York and the Center for Advanced Study in Education at the Graduate Center at the City University of New York. In this project, undergraduate students who are enrolled in the required courses for secondary science education at City College work as Explainers[3] at the New York Hall of Science for at least 7 h, weekly, through their third and fourth years of undergraduate work. All Explainers are required to participate in Explainer training and work tasks; however, the New York program

[3]Explainer is referred to with a capital "E" because it is understood in the ISI field as an official job title with a specific job description. When used with a capital E, the word implies a floor staff member who engages visitors in dialogues at the exhibits.

Explainers are also preservice teachers, and thus they have the further opportunity to take their museum experiences and reflect on them during their education coursework. As Explainers they learn how to engage visitors of all ages through a variety of interactive exhibits and public demonstrations. They can also assist with after-school programs, field visit workshops and school outreaches. Undergraduate students who apply to the New York program are pursuing a major in one of the sciences: biology, chemistry, physics, or earth science and are selected in their third year of study. Because recruitment is conducted through all local New York City colleges, the resulting New York program corps is diverse in socioeconomic status, ethnicity, and religion, as is true for the rest of the Explainers.

Two mechanisms were developed to enhance the integration between the Explainer experience and the formal university coursework. First, project staff coteach some of the mandated courses with college faculty. That role includes customizing the syllabus so that assignments and discussions can take advantage of the Explainer role. In addition, faculty from the college familiarize themselves with both the resources of the science center – the unique environment that exists for teaching and learning – and the New York program's goals. The museum staff learns about the state-approved elements of each course syllabus, and become familiar with state and national standards necessary for secondary science teaching.

Second, a conceptual/pedagogical frame of reference that is applicable to instruction in science education is necessary to assist the preservice teachers in developing knowledge, skills and dispositions as praxis. The New York program designed a framework to foster a common language about instruction in both the formal college setting and the multiple settings at NYHS. The framework consists of five components that were identified by the project team as being central to instruction and are functional in guiding science education activities in real time. The five components of the framework are: Identifying the Big Idea; Engaging the Learner; Making Student Thinking Visible; Introducing New Science Ideas; and Reflection/Assessment. The framework has been used to inform various course syllabi and to organize elements of exhibit and demonstration training at the museum.

The Extended Practicum Beyond the Classroom Option Program

Extended Practicum Beyond the Classroom Option (hereafter referred to as the Vancouver program) is based on a successful pilot study discussed earlier, where preservice teachers from the University of British Columbia's Teacher Education Program had semester-long practicum experiences in the Vancouver Aquarium Marine Science Centre (Jenkins et al. 2007). After the pilot, the Vancouver program expanded to include two additional institutions during the 2005–2006 academic year, Science World at the Telus World of Science and Vancouver Art Gallery. Preservice teachers completed a 10-week classroom-based placement followed by a

3-week practicum at one of the aforementioned sites. In this chapter, we focus on data from the two ISIs in the expanded project. All preservice teachers were in the secondary education program at the University of British Columbia and had majors in biology, chemistry, physics, and art. All preservice teachers attended orientation at their assigned institutions before their classroom placement began. These sessions allowed them to have an orientation to the facility, become familiar with the educational offerings, and meet the staff.

The key objectives for preservice teachers to participate in the extended practicum through the University of British Columbia were to (1) learn to listen and respond to the K–12 audience in the informal context/milieu, (2) build on their teaching skills in thoughtful interaction in this same context, and (3) apply their developing pedagogical experience and practice helping students connect with the curriculum offered by the relevant informal context/milieu.

At the Vancouver aquarium, preservice teachers observed activities in the institution's galleries, delivered classroom workshops to K–12 students on field-trip visits, and developed new material for K–12 audiences. The 3-week practicum began with the preservice teachers shadowing the institution's staff, then team-teaching with the institution's staff, and finally teaching in the programs and exhibits on their own. At Science World, preservice teachers followed a similar protocol but focused more on exhibit-based teaching and associated programs suitable for facilitating learning in the museum's galleries.

Bloomfield Science Museum Jerusalem

Bloomfield Science Museum Jerusalem (hereafter referred to as the Jerusalem program) has been in partnership with Jerusalem Teachers College for Girls for the past 13 years in a program where undergraduate students that are preservice teachers from the College work as Explainers in the science museum once a week for a semester as a required part of their practicum experience (Brezner 2008). As other Explainers in this museum, they teach workshops, conduct demonstrations, and give guided tours for visiting K–8 school groups on their field trip to the museum. Each student leads workshops with up to two classes a day. Before that, the students attend 60 h of training over an intensive summer course for Explainers, to learn and experience the museum programs, exhibitions, and hands-on activities as well as to observe museum staff in action. The participants in the program are undergraduate women majoring in science and education and most of them are enrolled to become science teachers in elementary and middle schools. During the semester they are observed and get feedback from the college and the museum staff. Their program at the museum focuses on supporting teaching skills, the informal pedagogical methods that can be adapted for the classroom, and on the potential connections between teaching in traditional class and using nonschool settings as resources.

Emerging Evidence

Taken through a Bourdieusian lens, ISIs can be considered as a field or site where culture is produced/reproduced and transformed, being experienced as patterns having thin coherence and associated contradictions (Sewell 1999). These fields are structured around specific schemas and resources that different people (staff, teachers, and visitors, for example) use to meet their goals. Although the physical setting – building exhibits and objects – usually characterize the structure of an ISI, there are relevant invisible structures, like the founding mission and ideology of an ISI that mediate activity in that field. For example, since schemas can include ideas, beliefs, values, and conceptions about how to conduct activity in social life, the ideology of an ISI – whether an interactive science center or a natural history museum – will shape and enable the activity that happens in the museum field. The resources include physical objects, human beings, and symbolic entities such as space and time. William Sewell (1992) theorizes that schemas and practices are dialectically related to each other. As a preservice teacher works within the schemas in ISI settings, she develops spielraum and expands the array of practices she can use to teach science. Due to the dialectical relationship of schemas and practices, she has the potential to mediate the schemas in different fields. That is, she has gained agency – the ability to appropriate schemas and resources to change the structures in other fields (i.e., such as a formal classroom).

Although the three museum–university collaborations we discuss in this chapter are different in implementation, they were all transformative in that they enabled preservice teachers to develop spielraum characteristic of teaching in a museum setting, yet beneficial to their future roles as classroom teachers. Four common themes emerged across the three contexts: Preservice teachers are able to apply and practice different pedagogical techniques on the same topic and refine their teaching practices; teach a select group of topics to diverse learners; experience different teaching styles; and have greater opportunities for self-reflection and adapt their ideas on what it means to teach science. Each of these themes and related challenges is discussed and then illustrated with examples from one or more of the partnerships.

Same Topic, Different Audiences

Overwhelmingly, preservice teachers mentioned that working in an ISI helped them to practice and refine their teaching, especially in using constructivist pedagogy, as this is the guiding philosophy of many ISI program designs and enactments. Preservice teachers in the Vancouver and the Jerusalem programs stated that opportunities to repeat the same lesson with different audiences were useful because they were able to feel confident while enacting the lesson as written, but also being able to modify it according to the needs of participants from different grades.

Preservice teachers reported that teaching the same concepts to different audiences revealed the complexity and difficulties in teaching those concepts and the opportunity to repeat and attempt different strategies for teaching strengthened their ability to teach effectively. One teacher from the Jerusalem program states, "…to repeat explaining the same subject to different groups in different interactions… enables you to reach different needs of students and levels… in different ways… and to improve your way of teaching and understanding…" Preservice teachers felt that this opportunity could only exist in the museum, and not in traditional classroom practicum experiences. Preservice teachers could review videotapes of the classes they taught in the museum on their own and then review vignettes with the college faculty. They could then track their own changes and growth over time.

In the New York program, preservice teachers work for many months and have chances to work at the same exhibits day after day. Over four semesters of weekly logs completed by the preservice teachers, there was evidence of a shift from activity-based responses such as "I explained exhibits on the museum floor" and "I performed a chemistry and laser demonstration" to responses that reflected a more inquiry-based approach to teaching such as "I am helping kids understand exhibits by letting them perform the activities instead of me showing it to them." Preservice teachers are encouraged to audiotape their interactions at the exhibits. They record interactions at one particular physical science exhibit upon entry into the program and consistently thereafter. In listening to tapings at the same exhibit 6 months later, there are several changes from initial taping to the second taping. The most noticeable change is a marked decrease in didactic teaching or simple explaining at the exhibits. In the later tape, there is also more of an attempt to draw the child in (create engagement) and provide positive reinforcement for visitors' verbalizations with statements like, "Yes, I agree" or "Did I understand you correctly?" Another change evident between the two tapings is how the pre-service teacher gears the interaction towards certain Big Ideas so that the visitor could "take away" at least one primary concept about the content of the exhibit.

Patterns emerging from all three projects support the potential utility of preservice teachers assuming the role of museum staff to practice aspects of inquiry-based, constructivist science teaching and allowing aspiring teachers to practice teaching the same concepts multiple times to different people. Since each visitor is different and brings her own schema and practices to the interaction, the preservice teacher has to approach each experience as a new activity. While the topic and content may be the same, the interaction is structured by both the preservice teacher and the visitor, thus leading to a different enactment. As such, each act offers a fresh opportunity to develop teaching skills, anticipate and respond to comments and questions, and immediately assess learning and engagement while interacting with visitors. These are necessary skills for any effective science teacher, but the structures of an ISI allow a *preservice* teacher to develop such skills.

These same structures can also be limiting in certain ways. Preservice teachers sometimes felt that the practicum needed more diverse tasks. While being able to teach the same topic over and over to different audiences was useful for developing practice, they sometimes felt bored and wanted to try something different. In the

Jerusalem program, the pre-service teachers had a variety of topics to teach, however the program style was the same for each session – a workshop, a demonstration and a guided tour. To address this challenge of providing a diverse set of job responsibilities in the New York program, pre-service teachers were invited to participate in a broader range of work, time permitting. These work/training experiences can be ordered along a continuum that ranged from informal science education activities on the museum floor to science education activities in classrooms such as leading discovery labs, assisting with after-school programs and outreaches to school. Not all preservice teachers in the New York program take part in all types of work experiences, but all are required to at least engage in floor interactions with visitors. For those who are able to devote more time, the continuum of work experiences affords them the benefit of a deeper, more varied experience.

Work with Diverse Learners

Ana Maria Villegas and Tamara Lucas (2002) advocate for a coherent approach to culturally responsive teaching by redesigning teacher preparation curricula and providing preservice teachers with opportunities to rethink their own selves in the context of their students. They state:

> A crucial task of teacher educators in preparing prospective teachers to be responsive to a changing student population is to help them locate themselves along this dysconscious-to-conscious continuum and then to support their movement toward greater consciousness (p. 32).

In response to this statement, we again consider the structures that exist in an ISI. The physical context of the ISI is designed to foster social interactions (Falk and Dierking 2000) between people and between people and exhibits. It is often the role of ISI staff to facilitate interactions between the visitors and the exhibits – many times the ISI staff interacts with multiple visitors at once. ISIs, like the ones described in this chapter, attract economically and ethnically diverse visitors. Thus, preservice teachers in the role of ISI staff have the opportunity to learn how to interact with and teach a diverse population (where the diversity can even change from moment to moment!). Teachers can observe how culture plays a role in level of engagement. They can think about and practice various ways to work with students who may have various disabilities. They can also develop pedagogical approaches that allow them to successfully interact with students who may speak a different language than that of the host country. In the ISI setting, the preservice teacher can become more aware of himself or herself as a culturally situated being vis-à-vis the cultural situatedness of his or her future students. The museum setting has been described as a place for doing "identity work" (Rounds 2006) – a place where one comes to confirm existing identities or expand their identities to include the new resources they encounter (Adams 2007). Learning also expresses identity, so in learning to teach in a museum setting, a preservice teacher is developing and expressing an identity at once and this identity includes what he or she learns in his or her interactions with visitors. In these interactions, a preservice teacher can become more aware of how his or her schemas and practices (culture) afford his or her interactions with diverse people and vice versa. They can bring this learning, this expanded agency into their classroom practice as they continue their learning to teach diverse students.

When preservice teachers work as museum staff, they have opportunities to practice teaching a concept, gauge their success, reevaluate their approach, and immediately engage another visitor. Over time, they become unafraid to approach a new visitor or groups of visitors and venture into science conversations that do not have predetermined teaching or learning goals. Each experience allows them to build on prior successful interactions and increases their potential of being successful teachers. Each success creates an increased level of confidence and strengthens within them the notion that all people can learn given the right strategies and approaches. For both of us, this ability to practice teaching concepts to diverse audiences strengthened our skills as science educators and our personal experience becomes the reason why we have chosen to focus on this idea across the partnerships.

In all three contexts, preservice teachers' experiences consistently support the idea that informal learning organizations offer a unique environment for practicing the act of teaching with a variety of audiences who differ in age, race, socioeconomic status, and learning abilities. Preservice teachers in the program credit the exposure they received to working with heterogeneous audiences as important to their development as a teacher. In the Vancouver program, preservice teachers also valued the opportunity to work with students of all grades even though they were training for secondary school.

Preservice teachers increased their confidence to teach all different kinds of students, and strengthened their pedagogical skills. The experience helped them expand or confirm the grade levels they were interested to teach. They directly attributed their ability to quickly establish pedagogical relationships with visiting groups of students to their extended practicum experience. They increased their ability to gauge the audience, draw out their prior knowledge and engage them with the new ideas in a short amount of time. These teachers felt that they would not have developed those skills in only a traditional classroom-based practicum.

We believe that for a museum practicum to be effective, preservice teachers need to participate in a variety of pedagogical experiences over an extended period of time. Each of the three partnerships described engage preservice teachers for different time intervals. In the Vancouver program, preservice teachers spend 2–3 weeks in intensive experiences. At the Jerusalem program, they spend 1 day a week for one semester after a 10-day intensive summer orientation course. In the New York program, they spend 1 or 2 days a week for approximately 2 years. We have learned that over time, preservice teachers are moving beyond their comfort zones in their attempts to engage children with the big ideas behind the exhibits and to help them construct their own understandings about the exhibit. However, we need to document how much practicum time – on the museum floor with visitors – is sufficient to allow teachers to develop spielraum in this setting with diverse audiences.

Learning Alongside Different Museum Staff

In ISI settings, full-time museum education staff have different approaches to teaching the same content and/or corresponding exhibit. Each person develops a particular repertoire over time that is personalized to his or her teaching style. In all three settings, the preservice teachers worked with experienced museum staff that effectively modeled science teaching and learning in the museum setting. The preservice teachers were able to observe different staff members teaching the same content and base their own practice on what they observed. Since preservice teachers had opportunities to teach the same content to different visitors, they could attempt different strategies. They were able to learn and practice at once. Seeing different styles and different approaches to working with students exposed preservice teachers to constructivist pedagogies that they learned about in coursework. In particular, the Vancouver program preservice teachers state that they expanded their understanding of pedagogy. They also valued opportunities to collaborate with each other and the museum staff and articulated that such opportunities contributed to their sense of worth as an education professional. Once the participants become teachers, the Jerusalem program has learned that some of them continued to visit and even consult with the museum staff on their field-trip plans. The teachers have also mentioned that they implemented some of the museum's skills and methods in their teaching career.

However, there were issues with role clarification that emerged across settings. Part of the challenge in such partnerships is to articulate the role of the preservice teacher – whether they become staff in already existing roles or retain a separate identity. In each of the three sites we discuss in this chapter, the preservice teacher had a slightly different role. What the role was and how it fit into the organizational structure of the museum was important for success. For example, preservice teachers who worked at the Vancouver aquarium felt that they needed more clarification about the difference between the roles and tasks of the permanent museum floor staff and themselves. In both the New York and Jerusalem program, preservice teachers join the existing staffing structure and are responsible for all tasks that fall under the Explainer role, including group orientation and departure. Often, these tasks detract from their time to practice teaching. When the museum tried to exempt these Explainers from some of the non-pedagogical tasks, there was resentment from other Explainers. Still, there is value to integrating preservice teachers within the organizational structure because it is much more immersive into the museum culture, which includes social interactions and networking with people from different backgrounds, interests, and majors and it is least disruptive to the museum's own systems. Yet, a separate and special program for preservice teachers allows the faculty to focus on specific skills and experiences and everyone is clear on their roles for that specific time period.

The need for focused orientation related to the goals of the preservice programs also arose. In the Vancouver program, the preservice teachers felt that the museum orientation could have included more observations in the museum, integrated more of the expert staff to model lessons and less of training on logistical issues (i.e., bathroom locations). The New York program experienced a similar challenge where, while preservice teachers did receive the traditional orientation that all Explainers received, it was focused more on the logistics of working as an Explainer rather than on pedagogy. To address this challenge, a special half-day orientation was added specifically for those Explainers who were part of the New York program. This orientation focused on using the project framework for teaching where experienced staff modeled the use of the framework at exhibits, and preservice teachers learned about and discussed the different ways they can take advantage of the museum practicum experience. The Jerusalem program also developed a focused orientation just for preservice teachers beyond the mainstream Explainer training for similar reasons.

Opportunities for Self-Reflection

Julie Monet and Eugenia Etkina (2008) demonstrate that being able to conceptualize how one learns and how to identify strategies through which one learns are key components of one's professional development experiences. The environment of museum practicum program coupled with some form of journaling, online logs or blogs have the potential to elicit such self-reflection. Additionally, exposure to diverse teaching styles, different topics, and heterogeneous visitors triggered prompts for self-reflection possibly not available through traditional practicum methods. Working in an extended practicum at an informal institution allowed the Vancouver program teachers to reflect upon their own personal pedagogy. They were able to compare the formal and informal teaching and learning environments and become aware of their own preferences for how they approached teaching and what they liked about formal teaching. These teachers felt that the classroom practicum did not allow much time for self-reflection and when there was time, it was more advisor-driven while the reflection in the extended museum practicum was more self-driven.

In the Jerusalem program videotapes were used to facilitate self-reflection. Preservice teachers selected vignettes to show colleagues, professors, and museum staff. They used a rubric designed by the museum and college staff to assess and discuss elements of student-centered teaching in their practice.

In the New York program, some preservice teachers realized when their own teaching needed modification along with the notion that they would have opportunities to practice their modifications at the Hall. For example:

> Because of assignments due from the methods course, I have been analyzing almost every lesson I am involved in at the Hall of Science, comparing it to the cluster framework. This has allowed me to streamline my presentations, trying to keep in mind at least one big idea, or question that could bring out a student's thinking as well as be a usable form of assessment. (Center for Advanced Study in Education 2007, p. 36)

The weekly logs from the preservice teachers in the New York program suggest that they are not only acquiring concepts central to framework, but are also undergoing a shift in thinking about what it means to teach science:

> [observation of another Explainer] The Explainer that was working at the bio lab today, was using formative assessment by asking the kids what were they noticing when doing the experiments. These types of questions are important because the instructor or Explainer would know if kids are learning or not. (Center for Advanced Study in Education 2007, p. 35)

Evident from this statement from a preservice teacher, developing the schemas and practices to be able to self-reflect in low-stakes settings allows teachers to have agency in guiding their own learning progressions. They begin to recognize when their teaching style needs adjustment (based on feedback and reactions from learners) and are able to be agentic in doing what they need to do to adjust their practice. In the ISI setting, for example, they could observe another colleague teaching a similar lesson to learn a different approach/technique. They also have the opportunity to reflect on how they themselves learn by trying out different interactive exhibits and transfer their learning about their own learning into practice with visitors. Thus, in the ISI setting preservice teachers gain the tools to be agentic in their own professional development and growth as teachers.

Looking Forward

In this chapter, we describe the emergence of key ideas that are shared across the programs, in three different contexts, where a partnership with a teacher preparation program and an ISI supports a preservice teacher's ability to practice teaching content to diverse audiences, have opportunities to observe and interact with staff engaged in student-centered teaching practices, and have opportunities for reflection and building awareness of one's own self as a teacher. The program continues to exist in all three sites and project teams are gathering data to document the longitudinal growth and development in preservice teachers who have participated in museum-based practicum experiences. In all three programs, preservice teachers are being tracked so that we can learn how their ISI experience impacts their actual classroom teaching. The following vignette demonstrates what we expect to learn.

Researchers from the Jerusalem program interviewed a mentor teacher in a placement school. She described an instance where a principal was short-staffed and needed two different classes to be covered. Two preservice teachers from the Jerusalem program were present and volunteered to conduct the classes. Each teacher managed to conduct effective lessons without time for preparation and planning. When questioned as to why they felt so comfortable volunteering to conduct the classes, they reported that it was similar to conducting classes at the Bloomfield Science Museum Jerusalem. Although they did not have time for preparation, they had enough experiences to engage children in learning experiences for a 2-h class.

The mentor teacher was surprised that student teachers could have such comfort and confidence in volunteering to teach a class. In an interview 2 years after this event, one of the preservice teachers commented: “AAhh, it was in the beginning of our practicum in that school… there was a need to help and to enter another class with no teacher. So we did it. It was not such a big deal. It was like having one more group of children in the museum. Actually we both behaved as if we were in the museum. We even told them about an activity we loved to do there, and we hooked the children and even could connect it to the class syllabus.” They did not remember the occasion as a remarkable event because they were able to readily transfer the spielraum that they gained in the museum to the classroom. In all three sites, we are working to draw out the long-term impact and strengths that a museum practicum can offer as is visible in the experiences of this preservice teacher.

Although we are learning that ISIs are unique laboratories for learning how to teach, we have also realized that partnerships between museums and universities have to tackle certain challenges, such as institutional cultural differences between the ISI and the college setting. The approach to teacher education can be different from both the university and ISI perspectives, and require time and negotiation to foster the relationship. Gaining familiarity with each other’s contexts is crucial to appreciating what each partner brings as a resource for the partnership. To that end, we expect to continue our research in this area and hope that as we learn more about university–ISI partnerships for science education, similar projects will emerge around the world thus adding to the body of knowledge around different mechanisms for preparing effective science teachers.

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Chapter 77
Community Science: Capitalizing on Local Ways of Enacting Science in Science Education

Jennifer D. Adams

Violet was excited to show me the projects that her students produced as a result of the botanic garden collaboration. As a city graduation requirement, students were required to design and conduct an inquiry-based project on one of the science topics they learned in middle school. When she opened the trifold for one of her students' projects, I saw a neatly presented controlled experiment that compared plant growth with different soil additives. The student described his study and his interest in growing these particular plants–his family used these peppers often in their cooking. The trifold had a picture of one of the plants with a brilliant red pepper. The same plant next to the trifold in the classroom was verdant, but stripped of its fruit. I asked Violet what happened to the fruits? "He sold them!" she replied with a smirk and a shrug. "He knew peppers were expensive and people liked them so he sold the big one to a neighbor. I was mad with him because I wanted to have it for the science fair!" she added. In Violet's classroom, community science was more often than not brought to bear in her science lessons. Violet taught in a predominantly Caribbean-American middle school and she was also of Caribbean descent. Unconsciously, she created a hybrid classroom as she enacted the culture of the community in the classroom alongside the mandated curriculum and its requirements.

Her students' projects demonstrated a *recursive difference* enactment of science between school and community. This recursive difference means that each time the student moves between his classroom and his community, the science he learns and in which he participates in one field is a repetition of what was previously known with the difference of added learning and enactment from the other field. In this vignette, her student combined the knowledge of the usefulness of particular plants learned from his community with the science learned in the classroom to design and evaluate the results of his project and the combination proved to be successful in

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both contexts. It was successful by school standards because he followed the format and received a good grade on the project, and it was successful by his community science standards because he was able to grow and profit from selling the pepper. The teacher and I discussed the questions other students asked in her class and in the botanic garden, and many of these questions stemmed from their experiences with plants in their communities, both in New York and in their countries of origin.

Recursive difference occurs in a structure where students are encouraged in their efforts to integrate the knowledge from their two spheres of classroom and community. As Miyoun Lim and Angela Calabrese Barton (2006) note, "children cannot utilize the experiences they have outside of school in any complete and meaningful ways in school if they are not provided with support opportunities to do so" (p. 110). Students are engaged in an ongoing construction of knowledge about their natural world through their interactions and experiences in home and community. Often, these constructions and experiences are discontinuous with the science taught in schools (Lee 2003, p. 466). Recognizing that much of science learning happens in everyday experiences, it is becoming more vital to structure classroom experiences that allow students to bring their community-based understandings of science into the classroom, as Violet did with her students' projects. Within a framework of community science, teachers can frame classroom-based experiences to be relevant to students' lived experiences outside of the classroom. In the following sections of this chapter, I first define community science and discuss the importance of the construct to science teaching and learning. I then use the construct of community science to reframe and discuss several studies involving the role and impact of community science. I conclude with a discussion of implications for teacher education and further considerations in community science.

Framing Community Science

Community science is a term that has been used in psychology to describe research and health education initiatives that focus on improving the overall quality of life of a given community. Abraham Wandersman (2003) describes a major goal of community science as, "[improving] the quality of life in our communities by improving the quality of practice of treatment, prevention, health promotion, and education" (p. 227). In this definition, improving quality of life is central, albeit through projects and programs developed by experts to address the needs of the community. However, what is missing from this definition is agency from within the community. For me, it raises the following questions: How does the community know and understand scientific and health issues? How are science-related practices enacted in localized ways? How can these community understandings be used to structure formal science learning opportunities?

Community science recognizes that much of science learning happens in informal contexts. The recent National Research Council report, *Learning science in informal environments: People, places and pursuits*, focuses on the recent interest in informal science because of its potential to improve science education nationwide (Bell et al. 2009). Informal science includes the science that we learn in everyday activities (i.e., hobbies and personal interests) and in environments that were created with science learning as a goal (i.e. after-school settings and informal science institutions). What these contexts have in common is the free-choice, self-directed approach to science learning (Falk 2001). Whether embedded in a necessary activity (like farming) or a leisure activity (like visiting a museum or through exercise), in informal science the act of learning science is embedded in the activity and often in pursuit of other goals.

Community science also includes everyday understandings of science and the decisions people make on a day-to-day basis that involve using scientific knowledge, although the community members may not use the same terms and understandings as sanctioned by the dominant science community (henceforth referred to as Western Modern Science). Unlike citizen science, projects where citizens contribute scientific research, community science does not always have a goal to systematically collect data to address a problem. However, there are cases where community science and citizen science intersect. For example, the Contested Illness Research Group out of Brown University has a project that examines citizen science alliances with contested diseases (such as asthma and cancers that appear to have environmental etiologies). They studied research collaborations between citizens and scientists that identify and determine the causes and plan for remediation of contested environmental illness (e.g., McCormick 2007). Hence, citizen science projects can emerge from community science interests. Citizen science can be used in the service of community science projects; however, citizen science may not always be of service to the goals of the local community within which the project is conducted. Thus, while community science projects are always beneficial to the local community, citizen science projects are often aimed at larger goals (e.g., establishing global bird counts and migration patterns) that are only indirectly of benefit to a local community.

Community science has the following characteristics: (1) it is embedded in place and responsive to one's sense-of-place; (2) it is goal-oriented (beyond learning science, science learning becomes a means and not an end); (3) it incorporates various ways of knowing, understanding, and evaluating evidence (Bell et al. 2009), as well as what counts as evidence.

Embedded in Place: The Big 'Ole Park is Right There!

"Why couldn't we go outside to learn about trees? We were talking about trees in the classroom with this big 'ole park across the street. Why couldn't we go outside?" My sister is an assistant principal in a large urban high school complex not too far from my apartment, so I pass through the school to see her every now and then. Once her students graduate, they often return to "bug her," as she puts it. They visit her to update her on their lives and often the discussions lead to reflections about their high school experiences. During one of my visits, my sister recounted this conversation she had with one of her former students. Although it was a simple statement, it left a lasting impression on me as it made me think about missed opportunities in science teaching and learning when teachers fail to make use of local resources to teach science. What was even more jarring to me is that the school is physically situated in the community where the student lives and where the park is also located. However, as with many urban schools, the stone walls of the building create a physical separation between the culture of the surrounding community and the relevance of the curricula that are enacted within the building. My sister recounted:

> This particular student had no problems passing his chemistry class but had difficulty passing his Earth science class, and this prevented him from graduating on time. I asked him why he was having such difficulty with this course and he expressed how it was so boring and not useful. He then blurted out, "why can't we go outside to learn about the trees?" I shared this comment with my sister because I was both deeply touched by his statement and agreed with him. Why can't we study science from the trees or from the flowers or from bugs? Why can't we touch the dirt, chase bugs, taste the ocean, or listen to the wind? This student was a very logical person; he could solve mathematical and scientific problems but somehow couldn't grasp the basic concepts of "where trees get their nutrients" or "how flowers grow." Somehow he lost his natural scientific connection to nature and was crying out for what was natural to him – observing a physical tree. Students learn in different ways; however, all have a connection to nature that is innate and it needs to be tapped into. I believe that no matter the learning style or disability, we are all natural scientists. So why not tap into that scientist within by taking a walk to a nearby park to use our senses to learn about the natural world? Afterwards, follow-up with reading books and conducting research on the significance, growth, and life cycle of trees. Such adventures in science would not only satisfy all learning styles but the natural scientist's mind and connect students to the nature that is found in their communities.

This student lives in a community – a place that is his lifeworld, a place where he finds resources that enable him to reproduce culture. Lim and Barton (2006) describe "lifeworlds" as one's interaction with the physical, social, and emotional (and I include spiritual) dimensions of their communities. A part of this student's lifeworld includes his interactions with scientific phenomena, although they may or may not be explicitly viewed as science by this student and/or members of his community. However, they are a part of the dynamic interaction between schemas and practices (Sewell 1999)–the culture that the student enacts in his lifeworlds. David Gruenewald and Gregory Smith (2008) define place-based education as a "community-based effort to reconnect the process of education, enculturation, and human development to the well-being of community life" (p. xvi). I consider community science to be the science education facet of place-based education. It is the re/connection of the science that exists in the community with the science that is learned in school.

As such, community science creates a pedagogical structure that could allow for localized ways of enacting science to become central to the practice and discussion of science in classrooms, where it is becoming increasingly important to make connections between science as articulated in the curriculum and science as students experience it in their lifeworlds. Community science could also create an area or discipline of science education that would allow researchers and educators (both in formal and informal contexts) to collect a body of work that will further the goal of making classroom science more relevant to students' lived experiences. Community science is contextualized science–science that is shaped by people's sense-of-place.

Goal Oriented

Why Are There No Fresh Vegetables in My Neighborhood?

City-as-Lab is an NSF-funded GK-12 project at Brooklyn College with the goal of creating "fresh, engaging, contextualized science learning experiences [for students] that are focused on their own communities" (NSF Division of Graduate Education #0638718, PI Dr Wayne Powell). This project teams a doctoral student (a Fellow) with a classroom teacher to create learning experiences for students where the local environment/community is used as a context for learning science. One of the goals of the classroom project is to use Geographic Information Systems (GIS) to collect and analyze community-based data. I evaluated the first-year experiences of the doctoral fellows.

Ann's (one of the fellows) eyes lit up when she talked about her students presenting at a professional health and nutrition conference at an Ivy League health sciences institution. She described it as, "the proudest moment of my life," seeing her students excited about presenting their research to a professional audience. They were one of only two student groups at the conference. Her students live in Bushwick, Brooklyn a predominantly lower-income Latina/o and African-American neighborhood (80% of the students in her school were eligible for free or reduced lunch). Ann was paired with an art teacher who was teaching out-of-license in a science research class, of which she had minimal background knowledge. According to Ann, "she did collages with them on the days that I was not there." Ann is working on her doctorate in psychology with an interest in health behaviors. She showed the popular film *Supersize Me*, and included statistics about death rates in Bushwick that could possibly be health-related (e.g., diabetes, heart disease) to get students to think about a community-based project. Through these resources, including her knowledge of health behaviors, Ann unwittingly created a structure that allowed students to use their knowledge of the community to develop research questions and hypotheses. They knew of friends, family, and neighbors getting sick and/or dying of the diseases mentioned in class. They also knew that people around them ate a lot of junk food because, as the students noted to Ann, "there is nothing else to eat!" Over time, they developed hypotheses about what food choices exist, and developed a plan to see if they were correct. Armed with clipboards, students went out into the community and quantified the food sources and choices. They surveyed the number of fast food restaurants, *bodegas*, and supermarkets in the community, and went into each venue to survey the actual food choices available. They collected data from over 80 places and were able to map these data using the GIS.

I asked Ann to recall the point when she felt that her students were really "hooked" into doing the project. "Oh, when they were actually out in the community collecting data!" she responded. They cared about it because they were out with clipboards, collecting data and feeling important–feeling official (some people even thought they were health inspectors). The project became more personalized and they were acquiring the tools to study their life place, and thus engaged in a transformative science learning experience (Chinn 2006). They felt empowered that they were learning something about their community, and they noticed what was missing and demanded the deficiencies be remedied. A local shopkeeper began to stock more fresh fruits because the students made a point of visiting every day and requesting apples. They also felt empowered in being able to share what they learned with the community. A small group of students continued to work on the project during out-of-school hours. The students made professional connections at Columbia University, where they presented, which enabled them to be hired as research assistants for a summer at $14/hour. They were able to immediately use the skills that they gained from participating in the community-based project.

The empowerment that students felt indicates a revision to the Baconian adage, "knowledge is power," for it is knowledge in service of the knower's goal that is power. As Gale Seiler mentions, "knowledge itself is worthless and only acquires power in interaction with the knower's desires and purposes" (2001, p. 1004). The City-as-Lab project enabled students to use the context of the community to learn how to collect, analyze, display, and communicate data. The project took on a purpose for students when they were able to use their own knowledge of the community in designing a research project and share with their community the knowledge they gained from the project. When they realized that there was an injustice with regards to food choices, they demanded change. For them, this community science project had a goal that had longevity beyond simply completing a science project as an exercise just to receive a grade.

Emergent Opportunities Become Motives

Clifford Knapp (2008) describes teaching as a "process of creating climates and conditions that engage students in learning with others" (p. 8). Students learn from others both in and outside of the classroom. Community science lessens the boundaries between the school and community. The City-as-Lab project became relevant to students when it allowed them to connect with their community in empowering ways. Although the educator created the curriculum and learning goals (based on her expertise and goal of using a particular tool), her desire to use the community as the context for learning science created structures that allowed for community science to emerge as both the process and reason for her goals. And, through participation in community science, the students' goals of learning more about their community and enacting agency in making changes became central to the overall goals of the project and the educator. In Jrène Rahm's study of City Farmers, the goal of the project was to teach urban students how to successfully grow marketable produce (Rahm 2002). Students were engaged in their local environment in ways that were novel to them as urban denizens. The gardening project enabled students to build an ecological connection to their community, thus allowing them to create a more holistic perspective of their lifeworld. As a community science activity, this engagement enabled students to think about and ask questions that were relevant to their understanding of, and practice in, a science-based activity. Rahm analyzed the dialogues that occurred between the youths and the adult facilitators, namely the types of questions that the youths asked and the science content that emerged from those questions. She reported that questions emerged from the students' experiences–questions about science emerging from participation–and these led to creating a science learning structure where the goals were not to learn science, but to participate in the act of producing marketable produce which required a certain degree of scientific understanding on the part of the students. This study demonstrates the power of integrating scientific principles in practices and processes that enable students to realize their own self-determined goals in and for their community as opposed to learning scientific principles isolated from place and endeavor, which often is a practice of rote memorization, with minimal relevance beyond the end-of-unit examination. Community science enhances learners' abilities to know how to use science knowledge as a tool in pursuit of personal/community-based motivations and goals.

Contextualized Science in Hybrid Spaces: Clippers and Drums

Gale Seiler's (2001) study describes an informal lunch meeting of eight African-American young men to "talk about their lives, and talk about and do science-related activities" (p. 1006). In this lunch group, although the goal was learning science, the activity in the group was structured around students' personal interests and activities, and these were used as resources to discuss scientific concepts. In one example in Seiler's study, two students, Cyrus, who worked in a barbershop for a number of years, and Dawud, who was interested in drumming, used their own language and cultural resources to discuss physics-related concepts of vibration and sound. The students were discussing how to tune a drum and the following dialogue ensued:

22 *Dawud*: You take a key and tighten it. The lugs going down on the rim into the head. You tighten the head.

23 *Seiler*: And what does that do?

24 *Dawud*: Changes the sound. When it's tighter, it sound one way, and when it's loose, it sound another way.

25 *Cyrus*: It's the same way at my job, right? When I'm cuttin' hair, if the clippers don't sound a certain way, I take a screwdriver and twist the screw in the side. Somethin' getting loose. So if it gets low and slower or increase the sound and become faster.

Although they did not use the official discourse of science, it was very clear from their conversations that they had a good grasp of scientific concepts as they experienced them in their lifeworlds. This lunch group was a hybrid space created by community science. This was a space where scientific discourse and practices of both school science and community-based understandings of the natural world merged. There were ample opportunities for students to bring their funds of knowledge to bear as they created the curriculum and structured the discussions.

Rahm's and Seiler's studies were both situated in informal spaces where the science curriculum emerged from students' questions and interests. In both of these projects, the dialectical relationship between science as a context and contextualized science enabled rich explorations of science content while keeping it relevant to students' goals. And, in both of these instances, the role of the educator or adult facilitator was to create structures that enabled students to use their own resources – specifically, their cultural knowledge and sense-of-place – to create science learning opportunities for themselves.

Multiscience: Fruta/Infrutescência

Community science recognizes and values the various discourses and ways of knowing that occur in people's lifeworlds. It allows for diverse perspectives on scientific understandings. Geilsa Baptista and Charbel El-Hani studied a curriculum development project in a Brazilian public high school that "aimed at promoting a dialogue between scientific and traditional knowledge in the context of biology teaching" (2009, p. 503). For me, the term "dialogue" is key here, because it is in the dialogue–the language interactions–that we can begin to uncover and synthesize ideas as they appear in different cultural constructs and contexts. Language is a powerful means of expression through which culture is transmitted and the ideologies of language shape the way people interact and also confirm relations of power and privilege (Winford 2003). It can provide the means for alternative perspectives to be voiced, but it also can be used to reinforce a dominant and exclusionary perspective. Too often in science classes the only acceptable/valued discourse is that which uses scientific words and language to describe students' lived experiences, although their lived experiences may include the concepts, but not the language sanctioned by science, as evident in Baptista and El-Hani's study.

The Brazilian school in the study is situated in a small city and draws students from the city as well as the surrounding agricultural villages. Many of the rural students work in agriculture and will most likely return to agriculture after high school due to the limited availability of jobs in the city. Baptista and El-Hani created a curriculum intervention based on ethnobiology by first interviewing students to learn about their situated knowledge. They learned about what students knew about growing plants–biological or horticultural science–in the students' own terms. They documented the students' traditional knowledge and made connections between this knowledge and the Western Modern Science in their high school science curriculum. In the data presented, it was evident that students held complex scientific views about how the natural world worked in their agricultural context. The names that they used and the processes they described were not much different from what was presented in the science curriculum. The students were also clear that they did not want to abandon their community science to adapt to that of the classroom. One student in the study was quoted, "traditional knowledge is people's knowledge, of our people. The farmers here only know by the traditional name. Therefore, we should always know traditional knowledge to speak with the people here" (p. 513). Students in the study acquired a sort of bilingualism while taking the course. They knew that there were specific domains where each language and corresponding knowledge applied. Baptista and El-Hani noted, "science education should … aim at enriching the range of modes of thinking and ways of speaking that students have on hand to interpret their own lives and the world around them, by understanding scientific ideas and their domain of application" (p. 514). This echoes Edna Tan, Angela Calabrese Barton, and Miyoun Lim's (2009) notion of science as both a context and a tool. Students in this study seem to maintain a view of the world through their own cultural lens, in this case an ethnobiological lens based on their agricultural context. However, the designed curriculum enabled them to use science as a tool to deepen their understanding of the natural and manipulated world.

Similarly, June George (1999) explored what she calls, the "indigenous knowledge" of people in a rural coastal village in Trinidad and Tobago. George describes indigenous knowledge as that which is generated by people seeking solutions to problems in their everyday lives by drawing on cultural and other local resources available, and "by using a fair amount of intuition and creativity" (p. 80). George interviewed youth and elders in the village, asking questions that allowed them to discuss their indigenous knowledge. Through her studies, she was able to describe the relationship between indigenous knowledge and Western Modern Science (WMS) using four categories: (1) the indigenous practice can be explained in WMS terms; (2) a WMS explanation for the indigenous phenomena seems likely, but is not yet available (this is often the case with the local use of plants for ailments); (3) a link between WMS and indigenous knowledge is evident, but the underlying principles are different; and (4) indigenous knowledge cannot be explained in WMS terms. George devised these categories as a framework for educators to understand the range of, and relationship between, indigenous practices in the community and classroom science.

Both Baptista and El-Hani and George's studies call for science education to be more aware of the traditions and beliefs that exist in a community and learn where these aspects can intersect with the school curriculum. People actively learn and enact scientific knowledge in their community settings. However, in their community settings, the goal is not to learn science, to become an expert, but rather learning is motivated by the interests and goals of the learner (Bell et al. 2009*)*. It is important for us to consider how teachers could resolve conflicts between students' cultural constructs–the science learned in the community, and classroom science (Lee 2003). Community science offers a construct that ties students' sense-making in their lived experiences with the science that is learned in the classroom and how the classroom science could be more relevant to their goals and motives in their day-to-day lives.

Teacher Education for Community Science

Several of the studies discussed in this chapter call for more culturally sensitive pedagogies that tie the classroom-based science activities to the community-based lifeworlds of students. Okhee Lee (2003) states, “in order to provide effective instruction for students of diverse backgrounds, teachers require knowledge of both science disciplines and students’ languages and cultures” (p. 481). Although that is a tall order for teachers, especially with the multiple ethnicities and languages that exist in many classrooms, it is important that teachers have a working knowledge of cultures (and corresponding schemas and practices) that exist within the community–within students’ lifeworlds–in order to make effective correlations with science in the classroom. George (1999) mentions that teachers do not often have the time to carry out such research and called on education researchers to carry out studies that illuminate this community-based knowledge for teachers. While I agree with George, I also believe that teachers can take initiatives and develop habits-of-mind that bring to awareness the culture of the community. Below I describe two examples of teacher education that focus on community.

Educators need to have a deeper awareness of their own cultural constructs about science and how they influence what they teach. Richard Kozoll and Margery Osborne’s (2006) study of Keith, a Jamaican-American preservice teacher, presents a narrative of how he made his life experiences “meaningfully relatable to science in a manner that continues to inform his future…” (p. 165). The narrative and interpretation ranged from Keith’s childhood in Jamaica–his interactions with and observations of native fauna and flora–to his experiences with science in college. Kozoll and Osborne (2006) noted that, for Keith, there was a substantial degree of congruence between science and his lifeworlds, and this enabled Keith to use science as a context (Lim and Barton 2006) with which to view these worlds. Although respondents to the study questioned whether Keith’s story was truly one of success (Taylor 2006) or whether the enculturation into Western Modern Science was not ultimately another form of colonization (Luke and Weir 2006), I believe that this reflexive examination is an important exercise for science educators. However, they should be structured in such a way that allows teachers to build a more multiscience worldview. Allan Luke and Katie Weir (2006) claim, “his [Keith’s] childhood experiences with Jamaican flora and fauna would give him a broader and richer commonsense about the biological [natural] world than many of his fellow teachers … the educative process entails translating that commonsense and everyday knowledge into redefined critical takes on the world” (p. 197).

Elsewhere, several colleagues and I engaged in a cogenerative inquiry where we discussed our experiences with science and becoming science educators (Adams et al. 2008). We discussed the importance of creating a space where both students and teachers could recognize and reconcile their own cultural beliefs with that of Western Modern Science. A good example of such a space is one that was created by Pauline Chinn (2007) in Hawai’i. She enacted a workshop based on *Malama I Ka ‘Aina Sustainability*, an interdisciplinary science curriculum that connects the science curriculum to a Hawaiian worldview and sense of place. Embedded in the curricula and workshop are decolonizing methods, “critical communication strategies that engage participants in examining lives, society, and institutions in ways that challenge dominant perspectives” (p. 1253). Mathematics and science educators from several Asian countries and the USA participated in a 10-day institute where they learned about Hawaiian indigenous knowledge and participated in a series of “critical indigenous research activities” designed to bring to their awareness their conceptions of indigenous science and connections to place. Chinn found that after the workshop, teachers assessed indigenous science more positively and were more critical of the absence of local perspectives in their own curricula. She suggests that, “science teacher education incorporate active learning situated in contexts and issues that recognize personal, sociocultural, and ethical contexts of science” (p. 1263).

Clifford Knapp’s (2008) course, Integrating Community Resources in Curriculum and Instruction, is another example of a course that enacts community/place-based pedagogy. Principles of place-based education and experiential learning were used to frame students’ activities which were specifically designed to help them learn how to find, investigate, and integrate local resources into their curricula. Knapp (2008) lists several key characteristics of this educational approach:

> The surrounding phenomena provide the foundation for interdisciplinary curriculum development and contain ecological, multigenerational, and multicultural dimensions. Students and teachers are encouraged to cross the boundaries between the school and the community and become involved in a variety of constructive ways. Learners are expected to become creators of knowledge as well as consumers of knowledge, and their questions and concerns play central roles in this process. They are assessed on the basis of how this knowledge contributes to the community’s well-being and sustainability, not just on how well they are prepared to earn a living. (p. 13)

By engaging preservice (and in-service) teachers in activities based on these principles, they can acquire the lifelong tools that would enable them to learn about and use local resources in whatever context they teach. Curious about the long-term impact of the course, Knapp conducted what he describes as a nonscientific poll and contacted some of his former students to ask them what they remembered from the course and how they are using some of the ideas from the course in their work as educators. He found that these students valued the activities in the course and were able to apply aspects of the course to their teaching. The design principles of this course could be used to focus teachers on community science–investigating those people and places that are representative of and resources for science as enacted in the community.

Thus, teacher education for community science should incorporate methods that allow teachers to engage in activities that encourage them to learn about their own identities, to explore their own beliefs about science and teaching science and to discover what science means to others, especially to the members of the communities where they teach. This can be accomplished by engaging in decolonizing methods as described by Chinn (2006), allowing teachers to practice teaching in low-stakes, diverse environments (Gupta and Adams this volume), and using critical methodologies in teacher education, like cogenerative dialogues (Tobin and Roth 2005) that allow teachers to discuss, imagine, and create a true praxis of community science in the classroom.

Sustainability and Community Science

Community science has the potential of attenuating the borders between the classroom and the community. This will become increasingly important as the schools are becoming microcosmic representations of globalization, along with the increasing diversity and detrimental emphases on abstract "universal concepts," rather than those grounded in the lives of students (Carter 2012). With this in mind, science educators need to be aware of how sociocultural issues, like cultural diversity, identity, and power influence science teaching and learning. Concepts from postcolonial theory, anthropology, and sociology urge science educators to reexamine issues of cultural diversity, identity, globalization, and inclusivity in science education (Zembylas and Avraamidou 2008). Lyn Carter (2008) identifies three areas of interest in sociocultural science education and research: (1) the challenge of Western science's claims of universal truth and objectivity; (2) cultural and linguistic diversity and its encounter with the normative culture of science education; and (3) the new transdisciplinary field of sustainability science. All of these areas are addressed by community science as it is responsive to diversity in culture and meaning, recognizes polysemicity in the interpretation of lived experiences around science, and could provide a framework for sustainability education. With global interest in creating more sustainable practices for the health of the environment, it is important to create a collective definition of sustainability–one that has a more holistic view of science. It is important to make the definition of sustainability relevant to people's lived experiences so that they can make informed decisions that will not only improve the quality of their lives, but also further the collective effort toward a sustainable future.

Carter (2012) refers to sustainability as a globalization discourse that addresses the key issue of "how to best effect the transition towards a sustainable future." Especially with the visible effects of global warming (such as media images of melting glaciers and notable changes in weather patterns), there is an increasing concern about preserving our natural resources and the health of our planet. Carter cites, "global sustainability issues highlight the impacts of the minority world upon the majority world or the Global South where the latter's resources are used for the benefit of the former, and where devastating environmental effects are experienced more acutely." Thus marginalized communities in urban areas are fractals of what occurs on a global scale.

Students are inundated with messages about conservation and sustainability. For example, there are recycling laws in New York City, more stores are offering reusable bags for free or a nominal cost, and the newer city buses have messages and motifs touting their greener use of energy. Research has shown that people of color and lower-income communities are more likely to live in areas of environmental degradation and/or with higher exposure to environmental toxins (Jones and Rainey 2006) and/or live in areas with diminishing levels of biodiversity (Kinzig et al. 2005). Although there are few studies about people of color's perceptions of environmental issues, it is suggested that those same communities tend to have the view that environmental problems in their communities have not been dealt with by governmental agencies in a just, equitable, and effective manner (Jones and Rainey 2006). So, although students in marginalized communities are surrounded by environmental or "green" messages, I wonder if they view these messages as something that does not apply to them. A graduate student (who is a Caucasian female) in one of my education research classes (she was researching recycling in schools) noted that some of the students she encountered (mostly of African descent or Latino) viewed recycling as a "White" thing. With these perceptions in mind, it is not only important to make students aware of the connection between their individual|collective (community) actions, but it is also important to structure activities that allow them to feel agentic in making changes necessary for the health of their community and environment. As in the City-as-Lab project described above, the actions that students made both as individuals and as a part of the collective of their classroom allowed them to realize changes in the larger collective of their community. Students can be empowered to make similar changes in their community in regards to sustainability as long as the learning activities are structured/situated *within* the context of the community. Community science is science embedded in place. Coupled with the philosophy and pedagogies of education for sustainability as outlined by Carter (this volume) community science could be a powerful way to engage students in local environmental issues and issues of sustainability. Michael Mueller and Deborah Tippins (2012, p. 866) note:

> Teaching students *how to fish* is rethinking the priorities of "an education from nowhere" where youth travel from science class to science class on a standardized journey of science concepts and facts. An education from/for *somewhere* corresponds with multiple or *plural* positive endpoints emphasizing healthy community and environmental outcomes.

This is a powerful statement about teaching students or providing structures for students to be informed citizens actively participating in and making decisions that positively affect the health and well-being of their community. Adapting the cliché think global, act local, within community science, students would think local, *en*act local, re/produce a local culture of sustainability that would, applying the butterfly effect, have a global reach.

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Chapter 78
Learning Science in Informal Contexts – Epistemological Perspectives and Paradigms

David Anderson and Kirsten M. Ellenbogen

Nature and Definitions of Informal Learning

The term "learning" means different things to different people. There is not a single comprehensive definition of learning in the field of science education or in other disciplines. Rather different definitions and views suit different contexts, worldviews, and research questions. Definitions of learning are strongly aligned with researcher paradigms, embedded in their ontology (belief about the nature of truth and reality) and epistemology (belief about how knowledge comes into being). What one believes about the nature of truth and the nature of knowledge are key influences on one's definition of learning and what counts as learning in the museum or in any other context. Moreover, values are embedded within paradigm and epistemological stance, thus what one values profoundly shapes and influences how one sees the world. This is particularly true of educators and researchers, since what one values about learning and knowledge profoundly influences the way in which education is practiced and the aspects of learning that become the focus of research studies. This is the case in the field of informal science education.

The term "informal learning" has traditionally been used to refer to at least two distinct but overlapping areas of study. Some researchers use the phrase to refer to learning that happens across all types of informal science education environments including designed, nonschool, public settings like science museums and after-school clubs as well as homes, on playgrounds, among peers, and in other situations

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where there is less of an explicitly designed and planned educational agenda. Others exclude designed environments and use the phrase informal learning to refer only to non-designed environments. Efforts to define out-of-school learning have frequently resulted in lists of characteristics that compare informal and formal learning. These dichotomized views are frequently oversimplifications of the characteristics of informal learning. The nature of learning in informal environments is, however, much more complex. Because such learning is complex, the attempt to dichotomize it is an attempt to reduce the complexity inherent in the intricate nature of learning and the diversity of views and values.

According to Sylvia Scribner and Michael Cole (1973), systematic organization is the variable that distinguishes informal and formal learning experiences. This definition of learning would categorize life experiences such as apprenticeships and ritualistic coming-of-age ceremonies as formal learning experiences. Rosemary Henze (1992) revealed that even some elements of day-to-day activities are ritualized and therefore could be considered a formal learning experience. Given the nature of many museum-based field trips or the structured nature of many museum-based after-school clubs, museums are, at least in part, a formal learning environment. Hence, the classification of learning contexts and experiences as formal or informal are somewhat arbitrary and can be argued and debated by researchers and educators depending on their epistemology of learning and the values to which they subscribe.

Research Paradigms and Methods

The manner in which social science research is practiced is shaped and influenced by numerous factors. Broadly speaking, the researcher's paradigm fundamentally influences all aspects of the research practice. In research investigations of learning, the researcher's views and beliefs about the nature of learning, what the researcher counts as learning, and the theories of learning to which the researcher subscribes shape the definitions of learning employed within a research investigation. The definitions of learning and what is valued as learning in turn profoundly influence the focus of the research investigation and in particular the research questions. Particular kinds of research questions will be posed within particular kinds of paradigms and certain research questions will be excluded from the investigation as a function of what is valued within the paradigm. In the practice of social science research, it follows that the research question of the study dictates the research methodology and methods. Certain kinds of research questions necessitate or are better answered by particular methods. Certain kinds of methodology and methods are embraced and even claim as being owned by particular paradigms and epistemologies of learning. Therefore, the influence of the research question, methodology, and methods are intertwined. In addition to the issues of research question and methodology, the approaches used to analyze and code data are heavily influenced by the paradigm employed. The researcher's beliefs about the nature of learning, and the values they hold of learning, will fundamentally have a bearing on the approaches used or employed to make sense of the data collected. In the same way there exists a connection between methodology and paradigm, and an interrelationship between the ways data are treated to create meaning and new knowledge, and the paradigm in which the research study (and researcher) is nested.

Research paradigm, research question, methodology and method, and analytical approaches collectively influence the kinds of knowledge produced through the research practice. The published research studies of the past 30 years[1] that investigate informal learning very often employ definitions of learning that are implicit, or unclearly defined. The theories of learning or education driving many of these research studies are often not overtly discussed, and rarely do the studies overtly express the paradigms in which the research is situated or elaborate on the researcher's epistemology of learning. Early informal science education research studies have often been criticized for being conducted in an atheoretical manner. One reason for this may be that research communities function within common paradigms and are not prompted to articulate their epistemological views or study design. Research communities are united by the kinds of conferences they attend, their professional networks, and the suite of research journals in which they publish – both community and forum are united by a commonality of views in which there are often unstated accepted common views of focus of research practice, and as a result overt description of what is valued is often viewed as unnecessary.

In an attempt to understand the kinds of knowledge that have been emergent from the field of informal science education we attempt a broad classification of past 30 years of literature by paradigm. Underpinning our classification are several assumptions. First, the field has evolved and changed these past three decades – research paradigms, the kinds of research questions posed, methods, and analytical approaches have not remained static but have undergone change. Second, we do not seek to judge paradigms as being deficient or superior, but rather seek to elucidate the views inherent within the paradigms and the rationale which drove the research given the period of the research and the issues confronting the field in that period. Third, we appreciate the difficulty and risks in classification of research – there are numerous research studies that equally, and effectively, straddle more than one paradigm and employ mixed methodological approaches to great effect (Johnson and Onwuegbuzie 2004). In this regard, we hold a similar view to that of Kadriye Ercikan and Wolff-Michael Roth (2006), and see the research that has been conducted in the field of informal science education as being classified along a continuum of paradigm.

Although there are many ways to conceptualize the documented research on science learning in informal contexts, from an archetype and methods perspective the literature in the field can broadly fall into three categories of paradigms – positivist–decontextualist, relativist–contextualist, and the critical theorist.

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[1] The last 30 years have been a period of great growth for research on informal science education, but there are examples of this research that date back as far as the mid-1860s.

Three Paradigm Perspectives

Objective Epistemology Embodied in Positivist–Decontextual Paradigms

Studies situated within a positivist–decontextual paradigm flourished in the 1970s but still rightly have a place today. These kinds of studies often employ psychometric and behaviorist approaches with experimental designs and quantitative data analysis (Nelson and Narens 1990). They are characterized by approaches that often attempt to establish truths by statistical means where comparative differences of $p < 0.05$ become accepted truths and $p>0.05$ are discarded as not meaningful. Positivist–decontextualist studies are characterized by an approach to research that seeks simple answers to the complex world of the visitor as learner in the museum environment or answers to questions that can be generalized to populations and demographics. Such approaches seek to remove contextual factors and any resultant uncertainties (Popkewitz 1984) and often use a single method with which to understand learning. Proponents of this paradigm argue there is an objective reality to be discovered and that truths about the nature of learning can be universally generalizable.

Sue Allen et al. (2007) described the ways in which researchers operating in this paradigm attempt to reduce complexity. This approach reduces complexity by distilling the complicated world into fewer, well-defined variables that may either contribute to a specific outcome or be ruled out as not contributing to it. Studies in social psychology, for example, often extract a limited number of variables from complex contexts to effectively determine principles that can be applied back to the complex contexts. Controlled experimental research has been conducted in informal learning contexts, but has had to overcome the logistical difficulty of assigning control groups in an informal environment.

The earlier years of science education research, including informal science education, were heavily influenced by behavioral psychologists who held an objectivist epistemology. They embodied positivist paradigms that produced studies that often employed a psychometric approach and relied heavily on experimental research design, and quantitative statistical data analysis. Research studies that focused on investigating the attraction and holding time of exhibits, for example, were conducted within an objectivist epistemology. For example, some empirical studies have focused on what people do with exhibits (e.g., Screven 1976, 1992). These studies focus on the inputs and outputs of the exhibit experience more than the specifics of the interactions during the exhibit experience. However, running parallel with the field of science education research, some investigators of informal learning environments questioned both the value and meaning of objectivist epistemology. This led to the emergence of studies which sought to understand learning from more direct observations, studies of moment-by-moment interaction, and consideration of social factors that were not common in a positivist–decontextualist paradigm.

Interpretivist Epistemology Embodied in the Relativist–Contextualist Paradigms

Studies within a relativist–contextualist paradigm emerged in the 1980s and 1990s and have produced highly ethnographic or phenomenologically based studies with very qualitative descriptions of learning in contexts. A relativist–contextualist paradigm regards factors like visitor agendas, motivations, and sociocultural identities as highly influential and important in relation to the development of learning. Researchers who take this perspective emphasize the importance of the natural ecology of the learning environment. These studies are typically qualitative and interpretivist in nature. They use research methodologies that recognize and account for the complexity of the learning environment. But they may be limited to case studies or other research designs that have limited generalizability.

Relativist–constructivist studies frequently utilize multiple data forms that better interpret and understand the nature of learning in informal contexts in a descriptive manner. Proponents of this paradigm argue that these kinds of research questions can more fruitfully assist educators and museum staff in understanding (and in turn improving) learning processes and outcomes. John Falk and Lynn Dierking's (2000) contextual model of learning is one example of an attempt to in part underscore the great complexity inherent in museum studies by separating the experience into four main components (physical, personal, sociocultural realms and time), each of which is a complicated world unto itself.

Most researchers within this paradigm would contend that learning in and from experiences in informal contexts involves a construction by the visitor of their own meanings and understandings. Meaning and understanding vary greatly depending upon the background, experience, interests, and knowledge a visitor brings to the experience. These include the visitor's social group, their sociocultural identities and physical context of the institution itself (e.g., Schauble et al. 1997; Silverman 1995). Hence, a museum exhibition or a museum program alone does not predict visitor learning in a way that studies situated in the positivist–decontextualist paradigm often assumed. Rather, it is the factors intrinsic to the visitors themselves interacting with the museum contexts that result in myriad learning processes and outcomes.

It is also important to appreciate that much of the research on impact and learning in museums has considered the individual (visitor) as the unit of analysis; yet relativist–contextualist paradigms have also provided valid and useful perspectives that attempt to understand learning that results from experiences in informal settings with different (larger) scales. Informal experiences, like those of visiting a museum, for instance, are very often social experiences and therefore units of analysis that consider the impact of the exhibitions on whole groups are also a valid way of interpreting and understanding learning. For example, numerous studies including the early studies of D.D. Hilke and John Balling (1985), and Paulette McManus (1987) as well as the more recent work of Adriana Briseno, David Anderson, and Ann Anderson (2007), have investigated the impact of museum experiences on family groups or even an entire community as in the case of John Falk and Martin Storksdieck's (2005) study. Other studies in this category include research that expands definitions of learning to include: developing disciplinary-specific knowledge, such as the big ideas and processes of science (Ash 2003; Crowley and Jacobs 2002); talk as a process and product of the museum experience (e.g., Borun et al. 1998; Crowley et al. 2001); and appropriating the language of science (Ellenbogen 2002, 2003).

A relativist–contextualist holds the view that learning is not reducible to a singularity, but rather a dynamic, multidimensional mosaic in a state of continuous development. Capturing continual development is not necessarily compatible with control groups and comparisons. For example, David Anderson's (1999) study – a within subject design study – which elucidated the highly complex nature of students' learning from science museum experiences, and in particular, the dynamic multiplicity of knowledge construction processes that students enact simultaneously. A positivist–decontextualist perspective offers consistent opportunities to provide strong evidence for learning, while a relativist–contextualist perspective presents inherent complexities in understanding learning that may be daunting to comprehend let alone investigate. The rewards for deeper understanding of visitor learning, however, are immense, since deeper understanding of learning has the capacity to better inform the design and development of exhibitions and programs from a grounded theoretical perspective, and improve the quality of visitors learning in all kind of contexts.

Critical Theorists Epistemology

Researchers within this domain hold a view that researchers in the field have for a long time been looking at the wrong issues and phenomena – and even, employing the inappropriate cultural lens of what we mean by the nature of learning. This epistemology, and inherent questioning of values, pushes the envelope about commonly held definitions of learning. Critical theorists advocate that the outcomes that arise from experiences in museums or other life experiences are highly complex and often inappropriately understood through definitions of learning more appropriate to formal education. Contemporary definitions of learning in the field of informal learning appreciate that there are multiple domains – affective, appreciative, aesthetic, moralistic, motivational, social, and identity, to name a few – all of which are much broader than a conception of the cognitive domain, but are, however, all inextricably and holistically interlinked with each other. It is both valid and often necessary to attempt to understand the parts in order to understand the whole, and, hence an examination of any single part is not a valid representation of the whole. Thus, examination of any single domain must be appreciated in the context of other domains.

Consider, for example, the power of moving beyond a single learning environment. Much of what we know about learning in science centers comes from evaluation studies – assessments of whether an exhibit or program has been successful according to a museum's stated objectives. Studies have typically addressed important questions about signage, exhibit features, or other issues specific to the design of exhibits or programs. Most of these studies are purposely limited to the museum context due to an explicit, pragmatic goal or due to a lack of resources. These studies also tend to be categorized as formative or summative studies, terms first proposed by Michael Scriven in 1967 to discuss evaluation of school curriculum. The twin approach of formative and summative evaluation is based on the assumption that a project will work through implementation problems and reach the point of a stable, fixed implementation that can be assessed one final time as a summative study. This approach is appropriate for much of the work that occurs in informal science education. Some projects, however, are based on complex systems and include nonlinear implementations that produce context-specific understandings to inform ongoing innovation. Transformative projects are likely to be a poor fit for the traditional formative–summative evaluation approach. The fields of education research and evaluation have validated innovative approaches such as design based research (e.g., Barab and Squire 2004; Brown 1992) and developmental evaluation (e.g., Patton 2008) to accommodate studies that embrace complex systems.

What would museum learning research look like if it were to take a learner-centered perspective that was unconstrained by limits on time and resources? There have been significant efforts to go beyond a single informal learning experience and track the impact of long-term variables (e.g., prior knowledge, interest, motivation) over multiple informal learning experiences. Investigations such as Rosemary Henze's (1992) study of learning across a community or David Anderson and Samson Nashon's study (2007), of student learning in classroom and amusement park contexts are exemplars that embrace such a paradigm. Some of these studies also include changes in identities as part of learning. Specifically, they examine how people view themselves, how they present themselves, and how others see them (e.g., Holland et al. 1998).

Some researchers and theorists such as Yvonna Lincoln and Egon Guba 1985, argue that methods that reduce or embrace complexity rest on fundamentally different underlying assumptions; they are incommensurable and should never be used within a single project or study. For example, the search for the typical experience is in conflict with the pursuit of multiple constructed realities; and purposive sampling violates many of the assumptions made by the statistical tests used in cause-and-effect, objectivist studies. Others, including Michael Quinn Patton (2002) argue that combining methods and even whole methodologies can provide a form of triangulation that strengthens the overall findings, provided the approaches are not mixed haphazardly. He describes developmental evaluation as Sue Allen et al. (2007) provide examples of this for museum-based research. Researchers can use random sampling techniques when timing and tracking visitors in exhibitions. Results of a timing-and-tracking study will generate data like average hold time at individual exhibits, which can be used in conjunction with qualitative interviews with visitors using those exhibits. Together, these studies would not only reveal patterns of usage throughout the exhibition, but also underlying connections between factors like visitors' previous museum experiences or their interests and their use of the exhibition.

Future Directions

Two critical areas of future work for research are identified in the recently commissioned review by the National Academy of Science's *Learning Sciences in Informal Environments: People, Places, and Pursuits* (Bell et al. 2009). In order to build the field of informal learning environments, researchers first need to build and test common theoretical frameworks, specifically, being more consistently explicit about stating theoretical frameworks and their epistemological positions, testing theoretical frames that exist in the field, and exploring the applicability of theoretical frames from other fields.

The second critical area for building the field is identified as stronger interdisciplinary perspectives. Research on informal science learning environments already draws upon multiple fields. Commitment to interdisciplinary teams, that also balance research and practice, will inform theory development in the field. Strict definition of research paradigm has compartmentalized the future directions of research into informal learning in unmeaningful ways (Ercikan and Roth 2006). Rather, abstraction from multiple perspectives including methodological and analytical approaches and broader conceptions of learning hold the promise of emergent knowledge that will be transformative of practice to the betterment of visitor learning. No single definition of learning unites informal learning research, and moreover, changes in paradigm have shifted and continue to shift both the focus and locus of research direction and resulting corpus of knowledge in the field.

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Part IX
Learning Environments

Chapter 79
Classroom Learning Environments: Retrospect, Context and Prospect

Barry J. Fraser

Because students spend up to 20,000 h in classrooms by the time they graduate from university (Fraser 2001), what happens in these classrooms and students' reactions to and perceptions of their educational experiences are significant. Although research and evaluation in science education rely heavily on the assessment of academic achievement and other valued learning outcomes, these measures cannot give a complete picture of the educational process. This chapter reviews over 40 years of research into conceptualising, assessing and investigating the determinants and effects of social and psychological aspects of the learning environments of science classrooms.

This chapter falls into three main parts. First, an introductory section provides background information about the field of learning environment (including alternative assessment approaches, historical perspectives on past work, and the distinction between school and classroom environment. Second, a section is devoted to a wide range of specific instruments for assessing perceptions of either the classroom or school learning environment. Third, an overview is given of several lines of past and current research involving environment assessments in science classrooms (including associations between student outcomes and the environment, use of environment dimensions as criterion variables in the evaluation of educational innovations, teachers' use of classroom and school environment instruments in practical attempts to improve their own classrooms and schools, differences between students' and teachers' perceptions of actual and preferred environment, person–environment fit studies of whether students achieve better in their preferred environment, combining quantitative and qualitative methods, school psychology, links between educational environments, cross-national studies, the transition between different levels of schooling, and typologies of classroom environments).

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Background: Historical Perspectives

Using students' and teachers' perceptions to study educational environments (the main approach used in past research) can be contrasted with the external observer's direct observation and systematic coding of classroom communication and events (Brophy and Good 1986). Henry Murray (1938) introduced the term *alpha press* to describe the environment as assessed by a detached observer and the term *beta press* to describe the environment as perceived by milieu inhabitants. Another approach to studying educational environments involves application of the techniques of naturalistic inquiry, ethnography, case study or interpretive research (see Erickson's chapter in this *Handbook*). Defining the classroom or school environment in terms of the shared perceptions of the students and teachers has the dual advantage of characterising the setting through the eyes of the participants themselves and capturing information which the observer could miss or consider unimportant. Students are at a good vantage point to make judgements about classrooms because they have encountered many different learning environments and have enough time in a class to form accurate impressions. Also, even if teachers are inconsistent in their day-to-day behaviour, they usually project a consistent image of the long-standing attributes of classroom environment. Later in this chapter, discussion focuses on the merits of combining quantitative and qualitative methods when studying educational environments as advocated by Ken Tobin and Barry Fraser (1998).

Over 40 years ago, Herbert Walberg and Rudolf Moos began seminal independent programmes of research which form the starting points for the work reviewed in this chapter. Walberg developed the widely-used Learning Environment Inventory (LEI) as part of the research and evaluation activities of Harvard Project Physics (Walberg and Anderson 1968). In collaboration with Edison Trickett, Moos began developing the first of his social climate scales, including those for use in psychiatric hospitals and correctional institutions, which ultimately led to the development of the Classroom Environment Scale (CES, Moos and Trickett 1974; Trickett and Moos 1973). The way in which the important pioneering work of Walberg and Moos on perceptions of classroom environment developed into major research programmes and spawned a lot of other research is reflected in historically significant books (Fraser 1986; Fraser and Walberg 1991; Moos 1979; Walberg 1979), more-recent books (Fisher and Khine 2006; Goh and Khine 2002; Khine and Fisher 2003), literature reviews (Fraser 1994, 1998, 2007), the American Educational Research Association's Special Interest Group (SIG) on Learning Environments which began in the mid-1980s, the initiation in 1998 of Kluwer/Springer's *Learning Environments Research: An International Journal*, and the birth in 2008 of Sense Publishers' book series *Advances in Learning Environments Research* (Aldridge and Fraser 2008).

The work on educational environments over the previous 40 years builds upon the earlier ideas of Kurt Lewin and Henry Murray and their followers. Lewin's (1936) seminal work on field theory recognised that both the environment and its interaction with personal characteristics of the individual are potent determinants of human behaviour. The familiar Lewinian formula, $B = f(P, E)$, stresses the need for research strategies in which behaviour is considered to be a function of the person and the environment. Murray (1938) was first to follow Lewin's approach by proposing a needs-press model which allows the analogous representation of person and environment in common terms. Personal needs refer to motivational personality characteristics representing tendencies to move in the direction of certain goals, while environmental press provides an external situational counterpart which supports or frustrates the expression of internalised personality needs. Needs-press theory was further popularised and elucidated by George Stern (1970).

Following the pioneering research of Herbert Walberg and Rudolf Moos in the USA, two further programmes of learning environments research emerged, one in the Netherlands and one in Australia. In the Netherlands, Theo Wubbels and his colleagues began ambitious programmatic research focusing specifically on the interactions between teachers and students in the classroom and often involving use of the Questionnaire on Teacher Interaction (QTI). This research programme is described in detail in this *Handbook* in the chapter by Theo Wubbels and Mieke Brekelmans and in many other sources including a seminal book by Theo Wubbels and Jack Levy (1993) and a special issue of the *International Journal of Educational Research* (Fraser and Walberg 2005; Wubbels and Brekelmans 2005). Subsequently, research on teacher–student interpersonal behaviour was spread to many countries by, for example, Rowena Scott and Darrell Fisher (2004) in Brunei Darussalam; Choon Lang Quek, Angela Wong and Barry Fraser (2005) in Singapore; Sunny Lee, Barry Fraser and Darrell Fisher (2003) in Korea; and Barry Fraser, Jill Aldridge and Widia Soerjaningsih (2010b) in Indonesia.

In Australia, Barry Fraser and his colleagues began programmatic research, which first focused on student-centred classrooms and involved use of the Individualised Classroom Environment Questionnaire (ICEQ, Fraser 1990; Fraser and Butts 1982). The ICEQ differs from the LEI and CES, which focus on teacher-centred classrooms, in that it assesses those dimensions that are salient in open or individualised classroom settings. Subsequently, Fraser was involved in developing other specific-purpose classroom environment instruments in Australia and cross-validating and applying them for a variety of research purposes around the world. As discussed in detail later in this chapter, these widely used questionnaires include the Science Laboratory Environment Inventory (SLEI), Constructivist Learning Environment Survey (CLES) and What Is Happening In this Class? (WIHIC).

Following the birth of learning environments research in the USA and pioneering programmes initiated in the Netherlands and Australia, this line of research began to spread to many parts of the world. In particular, Asian researchers made significant contributions to the field, commencing in the 1980s, which are reviewed by Barry Fraser (2002). In Singapore, significant research was undertaken by George Teh and Barry Fraser (1994, 1995); Angela Wong and Barry Fraser (1996); Swee Chiew Goh and Barry Fraser (2008); Choon Lang Quek, Angela Wong and Barry Fraser (2005); Hock Seng Khoo and Barry Fraser (2008) and Yan Huay Chionh and Barry Fraser (2009). In Indonesia, research was conducted by Wahyudi and David Treagust (2004); Barry Fraser, Jill Aldridge and Gerard Adolphe (2010a) and Barry Fraser, Jill Aldridge and Widia Soerjaningsih (2010b). In Korea, studies have been reported by Heui Baik Kim, Darrell Fisher and Barry Fraser (2000) and Barry Fraser and Sunny Lee (2009). In Taiwan, mixed-methods research was conducted by Jill Aldridge and colleagues (Aldridge et al. 1999; Aldridge and Fraser 2000).

It is useful to distinguish classroom or classroom-level environment and school or school-level environment, which involves psychosocial aspects of the climate of whole schools (Fraser and Rentoul 1982). School climate research owes much in theory, instrumentation and methodology to earlier work on organisational climate in business contexts. Two widely used instruments in school environment research, namely, Andrew Halpin and Don Croft's (1963) Organizational Climate Description Questionnaire (OCDQ) and George Stern's (1970) College Characteristics Index (CCI), relied heavily on previous work in business organisations. Two features of school-level environment work which distinguishes it from classroom-level environment research are that the former has tended to be associated with the field of educational administration and to involve the climate of higher education institutions. Despite their simultaneous development and logical linkages, the fields of classroom-level and school-level environment have remained remarkably independent. Although the focus of past research in science education has been primarily upon classroom-level environment, it would be desirable to break away from the existing tradition of independence of the two fields of school and classroom environment and for there to be a confluence of the two areas. In this chapter, however, the primary focus is classroom-level environment.

Murray's distinction between alpha press (the environment as observed by an external observer) and beta press (the environment as perceived by milieu inhabitants) was extended by George Stern, Morris Stein and Benjamin Bloom (1956) who distinguished between the idiosyncratic view that each person has of the environment (*private* beta press) and the shared view that members of a group hold about the environment (*consensual* beta press). Private and consensual beta press could differ from each other, and both could differ from the detached view of alpha press of a trained nonparticipant observer. In designing classroom environment studies, researchers need to decide whether their analyses will involve the perception scores obtained from individual students (private press) or whether these will be combined to obtain the average of the environment scores of all students within the same class (consensual press).

A growing body of literature acknowledges the importance and consequences of the choice of level or unit of statistical analysis and considers the hierarchical analysis and multilevel analysis of data (Bock 1989; Bryk and Raudenbush 1992; Goldstein 1987). The choice of unit of analysis is important because: measures having the same operational definition can have different substantive interpretations with different levels of aggregation; relationships obtained using one unit of analysis could differ in magnitude and even in sign from relationships obtained using another unit; the use of certain units of analysis (e.g., individuals when classes are the primary sampling units) violates the requirement of independence of observations and calls into question the results of any statistical significance tests because an unjustifiably small estimate of the sampling error is used; and the use of different units of analysis involves the testing of conceptually different hypotheses.

In his chapter in this *Handbook*, Jeffrey Dorman discusses the effect of clustering on statistical tests and illustrates this using classroom environment data. Because much classroom research involves the collection of data from students who are nested within classrooms, the hierarchical nature is important. Dorman considers the influence of intra-class correlations on tests of statistical significance conducted with the individual as the unit of analysis, and demonstrates that Type I error rates inflate greatly as the intra-class correlation increases. Because data analysis techniques that recognise the clustering of students in classrooms are essential, Dorman recommends that either multilevel analysis or adjustments to statistical parameters are undertaken in studies involving nested data.

Instruments for Assessing Classroom Environment

This section includes a description of four historically important and contemporary instruments, namely, the Learning Environment Inventory (LEI), Classroom Environment Scale (CES), Individualised Classroom Environment Questionnaire (ICEQ) and College and University Classroom Environment Inventory (CUCEI). Also included is a review of literature about: the My Class Inventory (MCI); Questionnaire on Teacher Interaction (QTI); Science Laboratory Environment Inventory (SLEI); Constructivist Learning Environment Survey (CLES); What Is Happening In this Class? (WIHIC) questionnaire; Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI); and Constructivist-Oriented Learning Environment Survey (COLES). Finally, this chapter considers several other classroom environment questionnaires, instruments for assessing school environment, and different forms of questionnaires (namely, preferred forms, short forms and personal forms).

Table 79.1 shows the name of each scale in each instrument, the level (primary, secondary, higher education) for which each instrument is suited, the number of items contained in each scale, and the classification of each scale according to Rudolf Moos's (1974) scheme for classifying human environments. Moos's three basic types of dimension are Relationship Dimensions (which identify the nature and intensity of personal relationships within the environment and assess the extent to which people are involved in the environment and support and help each other), Personal Development Dimensions (which assess basic directions along which personal growth and self-enhancement tend to occur) and System Maintenance and System Change Dimensions (which involve the extent to which the environment is orderly, clear in expectations, maintains control and is responsive to change).

Historically Significant Questionnaires: LEI, CES, ICEQ and CUCEI

Learning Environment Inventory (LEI)

The initial development and validation of a preliminary version of the LEI began in the late 1960s in conjunction with the evaluation and research related to Harvard Project Physics (Fraser et al. 1982; Walberg and Anderson 1968). The final version

Table 79.1 Overview of scales contained in some classroom environment instruments (LEI, CES, ICEQ, CUCEI, MCI, QTI, SLEI, CLES, WIHIC, TROFLEI and COLES)

			Scales classified according to Moos's scheme		
Instrument	Level	Items per scale	Relationship dimensions	Personal development dimensions	System maintenance and change dimensions
Learning Environment Inventory (LEI)	Secondary	7	Cohesiveness Friction Favouritism Cliqueness Satisfaction Apathy	Speed Difficulty Competitiveness	Diversity Formality Material environment Goal Direction Disorganisation Democracy
Classroom Environment Scale (CES)	Secondary	10	Involvement Affiliation Teacher support	Task orientation Competition	Order and organisation Rule clarity Teacher control Innovation
Individualised Classroom Environment Questionnaire (ICEQ)	Secondary	10	Personalisation Participation	Independence Investigation	Differentiation
College and University Classroom Environment Inventory (CUCEI)	Higher Education	7	Personalisation Involvement Student cohesiveness Satisfaction	Task orientation	Innovation Individualisation
My Class Inventory (MCI)	Elementary	6–9	Cohesiveness Friction Satisfaction	Difficulty Competitiveness	

Questionnaire on Teacher Interaction (QTI)	Secondary/Primary	8–10	Leadership Helpful/Friendly Understanding Student responsibility and freedom Uncertain Dissatisfied Admonishing Strict		
Science Laboratory Environment Inventory (SLEI)	Upper Secondary/ Higher Education	7	Student cohesiveness	Open-Endedness Integration	Rule clarity Material environment
Constructivist Learning Environment Survey (CLES)	Secondary	7	Personal relevance Uncertainty	Critical voice Shared control	Student negotiation
What Is Happening In this Class? (WIHIC)	Secondary	8	Student cohesiveness Teacher support Involvement	Investigation Task orientation Cooperation	Equity
Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI)	Secondary	10	Student cohesiveness Teacher support Involvement Young adult ethos	Investigation Task orientation Cooperation	Equity Differentiation Computer usage
Constructivist-Oriented Learning Environment Survey (COLES)	Secondary	11	Student cohesiveness Teacher support Involvement Young adult ethos Personal relevance	Task orientation Cooperation	Equity Differentiation Formative assessment Assessment criteria

contains a total of 105 statements (or seven items per scale) that are descriptive of typical school classes. The respondent expresses degree of agreement or disagreement with each statement using the four response alternatives of Strongly Disagree, Disagree, Agree and Strongly Agree. The scoring direction (or polarity) is reversed for some items. A typical item in the Cohesiveness scale is: 'All students know each other very well' and in the Speed scale is: 'The pace of the class is rushed'.

Classroom Environment Scale (CES)

The CES was developed by Rudolf Moos and Edison Trickett and grew out of a comprehensive programme of research involving perceptual measures of a variety of human environments, including psychiatric hospitals, prisons, university residences and work milieus (Moos 1974). The final published version contains nine scales with ten items of True–False response format in each scale. Published materials include a test manual, a questionnaire, an answer sheet and a transparent hand scoring key (Moos and Trickett 1974; Trickett and Moos 1973). Typical items in the CES are: 'The teacher takes a personal interest in the students' (Teacher Support) and 'There is a clear set of rules for students to follow' (Rule Clarity).

Individualised Classroom Environment Questionnaire (ICEQ)

The ICEQ assesses those dimensions which distinguish individualised classrooms from conventional ones. The initial development of the ICEQ by A. John Rentoul and Barry Fraser (1979) was guided by: the literature on individualised open and inquiry-based education; extensive interviewing of teachers and secondary school students; and reactions to draft versions sought from selected experts, teachers and junior high-school students. The final published version of the ICEQ (Fraser 1990; Fraser and Butts 1982) contains 50 items altogether, with an equal number of items belonging to each of the five scales. Each item is responded to on a five-point frequency scale with the alternatives of Almost Never, Seldom, Sometimes, Often and Very Often. The scoring direction is reversed for many of the items. Typical items are: 'The teacher considers students' feelings' (Personalisation) and 'Different students use different books, equipment and materials' (Differentiation). The published version has a progressive copyright arrangement which gives permission to purchasers to make an unlimited number of copies of the questionnaires and response sheets.

College and University Classroom Environment Inventory (CUCEI)

Although some notable prior work has focused on the institutional-level or school-level environment in colleges and universities (e.g. Stern 1970), surprisingly little work has been undertaken in higher education classrooms which is parallel to the traditions of classroom environment research at the secondary- and primary-school levels. Consequently, Barry Fraser and David Treagust developed the CUCEI for use in small classes (say up to 30 students) sometimes referred to as 'seminars' (Fraser and Treagust 1986; Fraser et al. 1986). The final form of the CUCEI contains seven, seven-item scales. Each item has four responses (Strongly Agree, Agree, Disagree, Strongly Disagree) and the polarity is reversed for approximately half of the items. Typical items are: 'Activities in this class are clearly and carefully planned' (Task Orientation) and 'Teaching approaches allow students to proceed at their own pace' (Individualisation).

In an evaluation of alternative high schools, Barry Fraser, John Williamson and Kenneth Tobin (1987b) used the CUCEI with 536 students in 45 classes to identify more involvement, satisfaction, innovation and individualisation in the alternative schools. Working in computing classrooms in New Zealand, Keri Logan, Barbara Crump and Leonie Rennie (2006) used the CUCEI and found that its psychometric performance was not ideal.

My Class Inventory (MCI)

The LEI was simplified by Barry Fraser, Gary Anderson and Herbert Walberg (1982) to form the MCI for use among children aged 8–12 years. Subsequently, Darrell Fisher and Barry Fraser (1981) simplified the original version of the MCI, and then Barry Fraser and Peter O'Brien (1985) evolved and used a short 25-item version. Although the MCI was developed originally for use at the primary-school level, it also has been found to be very useful with students in the junior high school, especially those who might experience reading difficulties with other instruments.

The MCI differs from the LEI in four important ways. First, in order to minimise fatigue among younger children, the MCI contains only five of the LEI's original 15 scales. Second, item wording has been simplified to enhance readability. Third, the LEI's four-point response format has been reduced to a two-point (Yes–No) response format. Fourth, students answer on the questionnaire itself instead of on a separate response sheet to avoid errors in transferring responses from one place to another. The final form of the MCI contains 38 items (long form) or 25 items (short form). Typical items are: 'Children are always fighting with each other' (Friction) and 'Children seem to like the class' (Satisfaction). Although the MCI traditionally has been used with a Yes–No response format, Swee Chiew Goh and Barry Fraser (1998) modified it to involve a three-point frequency response format (Seldom, Sometimes and Most of the Time) and a Task Orientation scale, and then they used it in research in Singapore among primary mathematics students.

In Brunei Darussalam, Abdul Majeed, Barry Fraser and Jill Aldridge (2002) used an English-language version of the MCI among 1,565 lower-secondary mathematics students in 81 classes in 15 government schools. When Majeed and his colleagues removed the MCI's Satisfaction scale to use an outcome variable, they established a satisfactory factor structure and sound reliability for a refined three-scale version of the MCI assessing Cohesiveness, Difficulty and Competition. These researchers reported sex differences in learning environment perceptions and associations between students' satisfaction and the nature of the classroom environment.

In a small-scale evaluation of a K–5 mathematics programme that integrates children's literature called Project SMILE (Science and Mathematics Integrated with Literature Experiences), Deborah Mink and Barry Fraser (2005) used the MCI, attitude scales and qualitative methods among a sample of 120 grade 5 mathematics students in Florida. The implementation of SMILE was found to have a positive impact in that there was congruence between students' actual and preferred classroom environment.

In Texas, Linda Scott Houston, Barry Fraser and Cynthia Ledbetter (2008) used the MCI in an evaluation of science kits among a sample of 588 grade 3–5 students. As well as attesting to the validity of the MCI, data analyses suggested that using science kits was associated with a more positive learning environment in terms of student satisfaction and cohesiveness.

Christopher Sink and Lisa Spencer (2005) advocate the use of the MCI as an accountability tool for elementary-school counsellors. Using a large sample of 2,835 grade 4–6 students in an urban school district in Washington State, these researchers found that an 18-item revision of the MCI (assessing cohesiveness, competitiveness, friction and satisfaction) was psychometrically sound. Implications for elementary-school counselling programmes and practices and their evaluation are considered by the authors.

Questionnaire on Teacher Interaction (QTI)

As noted above, pioneering and programmatic research which originated in the Netherlands focuses on the nature and quality of interpersonal relationships between teachers and students (Créton et al. 1990; Wubbels and Brekelmans 2005; Wubbels et al. 1991; Wubbels and Levy 1993). Drawing upon a theoretical model of proximity (cooperation–opposition) and influence (dominance–submission), the QTI was developed to assess student perceptions of eight behaviour aspects. Each item has a five-point response scale ranging from Never to Always. Typical items are 'She/he gives us a lot of free time' (Student Responsibility and Freedom behaviour) and 'She/he gets angry' (Admonishing behaviour).

Although research with the QTI began at the senior high-school level in the Netherlands, cross-validation and comparative work has been completed at various grade levels in the USA (Wubbels and Levy 1993), Australia (Fisher et al. 1995b), Singapore (Goh and Fraser 1996), and a more economical 48-item version has been developed and validated in Singapore (Goh and Fraser 1996). Also, Fisher and Cresswell (1998) modified the QTI to form the Principal Interaction Questionnaire (PIQ) which assesses teachers' or principals' perceptions of the same eight dimensions of a principal's interaction with teachers. Further information about research involving the QTI can be found in Theo Wubbels and Mieke Brekelmans' chapter in this *Handbook*.

In Brunei Darussalam, Rowena Scott and Darrell Fisher (2004) validated a version of the QTI in Standard Malay with 3,104 students in 136 elementary-school classrooms and showed that achievement was related positively to cooperative behaviours and negatively to submissive behaviours. In Singapore, Choon Lang Quek, Angela Wong and Barry Fraser (2005) validated an English version of the QTI with 497 gifted and non-gifted secondary-school chemistry students and reported some stream (i.e. gifted and non-gifted) and sex differences in QTI scores. In Korea, a translated version of the QTI was validated and used by Sunny Lee, Barry Fraser and Darrell Fisher (2003) among 439 science students, and by Heui Baik Kim, Darrell Fisher and Barry Fraser (2000) among 543 students. In Indonesia, a translated version of the QTI was validated with a sample of 422 university students by Barry Fraser, Jill Aldridge and Widia Soerjaningsih (2010b).

Science Laboratory Environment Inventory (SLEI)

Because of the critical importance and uniqueness of laboratory settings in science education, an instrument specifically suited to assessing the environment of science laboratory classes at the senior high school or higher education levels was developed by Barry Fraser, Geoffrey Giddings and Campbell McRobbie (Fraser et al. 1995; Fraser and McRobbie 1995; Fraser et al. 1993). The SLEI has five scales (each with seven items) and the five frequency response alternatives are Almost Never, Seldom, Sometimes, Often and Very Often. Typical items are 'I use the theory from my regular science class sessions during laboratory activities' (Integration) and 'We know the results that we are supposed to get before we commence a laboratory activity' (Open-Endedness). The Open-Endedness scale was included because of the importance of open-ended laboratory activities often claimed in the literature (e.g. Hodson 1988). The SLEI was field tested and originally validated simultaneously with a sample of over 5,447 students in 269 classes in six different countries (the USA, Canada, England, Israel, Australia and Nigeria). Subsequently, it was cross-validated in Australia with 1,594 students in 92 classes by Barry Fraser and Campbell McRobbie (1995) and 489 senior high-school biology students in Australia by Darrell Fisher, David Henderson and Barry Fraser (1997).

Barry Fraser and Sunny Lee (2009) translated the SLEI into the Korean language for use in a study of differences between the classroom environments of three streams (science-independent, science-oriented and humanities). The sample consisted of 439 high-school students divided among these three streams. The Korean version of the SLEI exhibited sound factorial validity and internal consistency reliability, and was able to differentiate between the perceptions of students in different classes. Generally students in the science-independent stream perceived their laboratory classroom environments more favourably than did students in either of the other two streams.

Working with a sample of 761 high-school biology students in 25 classes in south-eastern USA, Millard Lightburn and Barry Fraser (2007) used the SLEI in an evaluation of the effectiveness of using anthropometry activities. Data analyses supported not only the SLEI's validity (in terms of factor structure, internal consistency reliability and ability to differentiate between classrooms), but they also suggested that there was a positive influence of using anthropometric activities in terms of both classroom learning environment and student attitudes.

Constructivist Learning Environment Survey (CLES)

According to the constructivist view, meaningful learning is a cognitive process in which individuals make sense of the world in relation to the knowledge which they already have constructed, and this sense-making process involves active negotiation and consensus building. Peter Taylor, Barry Fraser and Darrell Fisher (1997) developed the CLES to assist researchers and teachers to assess the degree to which a particular classroom's environment is consistent with a constructivist epistemology, and to assist teachers to reflect on their epistemological assumptions and reshape their teaching practice. Taylor and his colleagues reported sound factorial validity and internal consistency reliability for the CLES for samples of: 494 Australian 13 year olds in 41 grade 8 and 9 classes in 13 schools involved in an optional component of the Third International Mathematics and Science Study (TIMSS); and 1,600 grade 9–12 science students in Texas.

Working with a diverse sample of 1,079 students in 59 science classes in North Texas, Rebekah Nix, Barry Fraser and Cynthia Ledbetter (2005) reported strong support for the validity of the CLES. Following the removal of four items, each of the remaining 26 items had a factor loading of at least 0.40 on its own scale and less than 0.40 on all other scales, with a total of 45.5% of the variance being accounted for. Alpha reliabilities for different CLES scales ranged from 0.87 to 0.93 when the class mean was used as the unit of analysis, and all CLES scales were capable of differentiating significantly between the perceptions of students in different classes. An evaluation of an innovative science teacher professional development programme (known as the Integrated Science Learning Environment, ISLE, model) revealed that the students of these teachers perceived their classrooms more favourably than did the students of other teachers.

In a follow-up study in Texas, Nix and Fraser (2011) used Bruce Johnson and Robert McLure's (2004) newer and shorter 20-item version of the CLES in an evaluation of the implementation of the ISLE model over three semesters involving 17 teachers and 845 students. Use of CLES and qualitative data revealed that changing teachers' learning environment at the university level fostered similar changes in their students' middle-school classroom environments.

In a cross-national study of junior high-school science classroom learning environments, the English version of the CLES was administered to 1,081 students in 50 classes in Australia while a Mandarin translation was administered to 1,879 students in 50 classes in Taiwan. Jill Aldridge, Barry Fraser, Peter Taylor and Chung-Chih Chen (2000) reported sound validity (factor structure, reliability and ability to differentiate between classrooms) for both English and Mandarin versions of the CLES. Additionally, these researchers reported that Australian classes were perceived as being more constructivist than Taiwanese classes (especially in terms of Critical Voice and Student Negotiation).

Maria Peiro and Barry Fraser (2009) modified the CLES, translated it into Spanish, and administered the English and Spanish versions to 739 grade K–3 science students in Miami, USA. Analyses supported the validity of the modified English and Spanish versions when used with these young children. Strong and positive associations were found between students' attitudes and the nature of the classroom environment, and a 3-month classroom intervention led to large and educationally important changes in classroom environment.

In South Africa, Jill Aldridge, Barry Fraser and Mokgoko Sebela (2004) administered the English version of the CLES to 1,864 grade 4–6 mathematics learners in 43 classes. This led to the cross-validation of this version of the CLES for this population in terms of factorial validity, internal consistency reliability and ability to differentiate between classrooms. The primary focus of this study was to assist South African teachers to become more reflective practitioners in their daily classroom teaching. Through the use of the CLES in teacher action research, some improvements in the constructivist orientation of classrooms were achieved during a 12-week intervention.

When Heui Baik Kim, Darrell Fisher, and Barry Fraser (1999) translated the CLES into the Korean language and cross-validated it with a sample of 1,083 students in 24 grade 10 science students, results supported the factor structure and reliability of the Korean version, revealed statistically significant relationships between classroom environment and students' attitudes to science, and confirmed that students exposed to a new curriculum perceived a more constructivist learning environment than did students who had not been exposed to this curriculum.

In two other studies, Korean researchers collaborated with an American colleague in research involving the use of a Korean version of the CLES. As part of an action research project involving creating constructivist learning environments in grade 11 earth science classes, 136 Korean students responded to the CLES several times in a longitudinal study of the development of constructivist classrooms and students' attitudes (Oh and Yager 2004). Not only were there improvements in CLES scores over time, but students' attitudes to science became more positive as their classrooms became more constructivist. Jung-Il Cho, Robert Yager, Do-Yong Park and Hae-Ae Seo (1997) used this version of the CLES with 70 Korean high-school teachers who visited the University of Iowa for professional development programmes. When the CLES was administered three times (at the beginning and the end of workshops and 3 months later) to evaluate the programme in terms of the development of teachers' constructivist philosophies, initial improvements in CLES scores were found, but they were not retained over a longer time period.

In a study in Florida, Howard Spinner and Barry Fraser (2005) used the CLES with two separate samples of 53 and 66 grade 5 students undertaking an innovative mathematics programme called the Class Banking System (CBS). As well as cross-validating the CLES, these researchers reported that, relative to non-CBS students, CBS students experienced more favourable pre–post changes on most of the dimensions of the CLES.

John Cannon (1995) used the CLES in evaluating an elementary science methods course which was based upon constructivist epistemology and fostered various constructivist teaching and learning strategies. When the CLES was administered to 43 pre-service elementary teachers (mainly females) at an American university at the end of the course, CLES scales exhibited satisfactory reliability. Although median scores on CLES scales were lower than anticipated by the researcher-instructor, nevertheless, feedback from the CLES was productive in identifying areas within the methods course that were less consistent with constructivist epistemology and in motivating the researcher-instructor to re-examine and modify classroom practices.

Judy Beck, Charlene Czerniak and Andrew Lumpe (2000) used the five constructs of the CLES in a study of teachers' beliefs regarding implementing constructivism in their classrooms. Two samples of 47 and 203 teachers in Ohio responded to a modified version of the CLES as a measure of teachers' self-reported implementation of issues related to constructivism. Beck and colleagues reported evidence to support the reliability of the CLES and concluded that, if teaching in a constructivist fashion is desired in schools, then teachers' beliefs about this behaviour must first be considered.

Sharon Harwell, Shanon Gunter, Sandra Montgomery, Cheryl Shelton and Deborah West (2001) reported the use of the CLES in the USA in a collaborative action research endeavour between a regional university and a local school (grade 6 level) to monitor the alignment of classroom learning activities with a constructivist viewpoint while integrating technology into the curriculum. Teacher logs, teacher interviews and field notes from team discussion groups and classroom observations provided further understanding of interactions in the classroom. Harwell and colleagues reported satisfactory alpha reliability coefficients for all CLES scales for a small sample of approximately 60 students, but found no significant changes in student perceptions of the classroom learning environment over the duration of the academic year. Interpretation of results led teachers to construct a new set of questions and a new plan of action to bring their classroom learning environments into closer alignment with a constructivist perspective for teaching and learning.

In our previous study involving the use of the original 30-item CLES among 1,079 students in 59 classes in North Texas, we reported strong factorial validity and reliability (Nix et al. 2005). When Bruce Johnson and Robert McClure (2004) used the same original 30-item version in the USA with 290 upper-elementary, middle-school and high-school teachers and pre-service teachers, they also reported strong factorial validity and reliability. Nevertheless, Johnson and McClure developed a shorter and modified 20-item version of the CLES containing the same five scales. For a different sample of teachers and students at the upper-elementary, middle-school and high-school levels, Johnson and McClure reported that the new and more economical version of the CLES exhibited strong validity and reliability.

What Is Happening In this Class? (WIHIC) Questionnaire

The WIHIC questionnaire is the most-frequently used classroom instrument around the world today. According to Jeffrey Dorman (2008, p. 181), ‘the WIHIC has achieved almost bandwagon status in the assessment of classroom environments’. The WIHIC brings parsimony to the field of learning environment by combining modified versions of the most salient scales from a wide range of existing questionnaires with additional scales that accommodate contemporary educational concerns (e.g. equity and constructivism). Also, the WIHIC has a separate Class form (which assesses a student’s perceptions of the class as a whole) and Personal form (which assesses a student’s personal perceptions of his or her role in a classroom), as discussed in more detail later in this chapter.

Developed by Barry Fraser, Darrell Fisher and Campbell McRobbie (1996), the original 90-item nine-scale version was refined by both statistical analysis of data from 355 junior high-school science students, and extensive interviewing of students about their views of their classroom environments in general, the wording and salience of individual items and their questionnaire responses. Only 54 items in seven scales survived these procedures, although this set of items was expanded to 80 items in eight scales for the field testing of the second version of the WIHIC with junior high-school science classes in Australia and Taiwan. Whereas the Australian sample of 1,081 students in 50 classes responded to the original English version, a Taiwanese sample of 1,879 students in 50 classes responded to a Chinese version that had undergone careful procedures of translation and back translation. This led to the final form of the WIHIC containing the seven eight-item scales described by Jill Aldridge, Barry Fraser and Iris Huang (1999). For both the Australian and Taiwanese samples, Aldridge and Fraser (2000) reported strong factorial validity and internal consistency reliability and that each scale was capable of differentiating significantly between the perceptions of students in different classrooms.

A comprehensive and impressive validation of the WIHIC was conducted by Jeffrey Dorman (2003) using a cross-national sample of 3,980 high-school students from Australia, the UK and Canada. Confirmatory factor analysis supported the seven-scale a priori structure, with fit statistics indicating a good fit of the model to the data. The use of multi-sample analyses within structural equation modelling substantiated invariant factor structures for the three grouping variables of country, grade level and student sex. Dorman’s study supported ‘the wide international applicability of the WIHIC as a valid measure of classroom psychosocial environment’ (p. 231).

In a second study, Dorman (2008) used both the actual and preferred forms of the WIHIC with a sample of 978 secondary-school students from Australia. Separate confirmatory factor analyses for the actual and preferred forms supported the seven-scale a priori structure, with fit statistics again indicating a good fit of the models to the data. The use of multi-trait–multi-method modelling with the seven scales as traits and the two forms of the instrument as methods supported the WIHIC’s construct validity. This research provided ‘strong evidence of the sound psychometric properties of the WIHIC’ (p. 179).

Table 79.2 lists 21 studies that have involved the use of the WIHIC in various countries and in various languages. The first four studies in Table 79.2 are examples of cross-national research conducted in Australia and Taiwan in two languages by Jill Aldridge and Barry Fraser (2000), in Australia, the UK and Canada in English by Jeffery Dorman (2003), in Australia and Indonesia in two languages by Barry Fraser, Jill Aldridge and Gerard Adolphe (2010a), and in Australia and Canada by David Zandvliet and Barry Fraser (2005). The next five studies in Table 79.2 involved the use of the WIHIC in English in Singapore by Yan Huay Chionh and Barry Fraser (2009) and Hock Seng Khoo and Barry Fraser (2008), in India by Rekha Koul and Darrell Fisher (2005), in Australia by Jeffrey Dorman (2008) and in South Africa by Jill Aldridge, Barry Fraser and Sipho Ntuli (2009). The tenth and eleventh studies listed in Table 79.2 involved the use of the WIHIC, respectively, in the Korean language in Korea by Heui Baik Kim, Darrell Fisher and Barry Fraser (2000) and in the Indonesian language in Indonesia by Wahyudi and David Treagust (2004). The next two studies involved the use of an Arabic translation of the WIHIC in the United Arab Emirates by Cheri MacLeod and Barry Fraser (2010) and Ernest Afari and colleagues (in press).

The last eight entries in Table 79.2 are all studies that involved the use of the WIHIC in the USA, including three studies in California by Perry den Brok and colleagues (2006), Catherine Martin-Dunlop and Barry Fraser (2008) and Philip Ogbuehi and Barry Fraser (2007), one study in New York by Stephen Wolf and Barry Fraser (2008), and four studies in Florida by Linda Pickett and Barry Fraser (2009), Debra Allen and Barry Fraser (2007), Esther Robinson and Barry Fraser (in press) and Karen Helding and Barry Fraser (in press). Although the four studies in Miami all involved the use of an English-language version of the WIHIC, it is noteworthy that three of them offered students the option of responding to a version of the WIHIC in either Spanish or in English.

For each study involving the WIHIC in Table 79.2, details are provided not only of the country and language involved, but also the size of and nature of the sample. In Table 79.2, it also is noted that every study reported evidence to support the factorial validity and internal consistency reliability of the WIHIC; as well, the majority of these studies also furnished evidence of the ability of the WIHIC to differentiate between the perceptions of students in different classrooms. The second-last column of Table 79.2 identifies for which specific student outcomes the relationship between environment and outcomes were reported in each study (if applicable).

Finally, the last column of Table 79.2 identifies the unique contributions of each study. For example: Zandvliet and Fraser (2004, 2005) simultaneously investigated the physical and the psychosocial environment; Pickett and Fraser (2009) monitored the success of a mentoring programme for beginning teachers in terms of changes in their school classroom environments; Robinson and Fraser's (in press) study of kindergarten students and their parents revealed that, relative to students, parents perceived a more favourable classroom environment but preferred less favourable environment; and Helding and Fraser (in press) evaluated of the effectiveness of National Board Certified (NBC) teachers in terms of their students' perceptions of classroom environment.

Table 79.2 Details for studies that used WIHIC

Reference(s)	Country(ies)	Language(s)	Sample(s)	Factorial validity and reliability	Associations with environment for:	Unique contributions
Aldridge et al. (1999); Aldridge and Fraser (2000)	Australia Taiwan	English Mandarin	1,081 (Australia) and 1,879 (Taiwan) junior high science students in 50 classes	✓	Enjoyment	Mandarin translation Combined quantitative and qualitative methods
Dorman (2003)	Australia UK Canada	English	3,980 high school students	✓	NA	Confirmatory factor analysis substantiated invariant structure across countries, grade levels and sexes.
Fraser et al. (2010a)	Australia Indonesia	English Bahasa	567 students (Australia) and 594 students (Indonesia) in 18 secondary science classes	✓	Several attitude scales	Differences were found between countries and sexes.
Zandvliet and Fraser (2004, 2005)	Australia Canada	English	1,404 students in 81 networked classes	✓	Satisfaction	Involved both physical (ergonomic) and psychosocial environments
Chionh and Fraser (2009)	Singapore	English	2,310 grade 10 geography and mathematics students	✓	Achievement Attitudes Self-esteem	Differences between geography and mathematics classroom environments were smaller than between actual and preferred environments.
Khoo and Fraser (2008)	Singapore	English	250 working adults attending computer education courses	✓	Satisfaction	Adult population Males perceived more trainer support and involvement but less equity.
Koul and Fisher (2005)	India	English	1,021 science students in 31 classes	✓	NA	Differences in classroom environment according to cultural background

(continued)

Table 79.2 (continued)

Reference(s)	Country(ies)	Language(s)	Sample(s)	Factorial validity and reliability	Associations with environment for:	Unique contributions
Dorman (2008)	Australia	English	978 secondary school students	✓	NA	Multitrait-multimethod modelling validated actual and preferred forms.
Aldridge et al. (2009)	South Africa	English	1,077 grade 4–7 students	✓	NA	Pre-service teachers undertaking a distance-education program used environment assessments to improve teaching practices.
Kim et al. (2000)	Korea	Korean	543 grade 8 science students in 12 schools	✓	Attitudes	Korean translation Sex differences in WIHIC scores
Wahyudi and Treagust (2004)	Indonesian	Indonesian	1,400 lower-secondary science students in 16 schools	✓	NA	Indonesian translation Urban students perceived greater cooperation and less teacher support than suburban students.
MacLeod and Fraser (2010)	UAE	Arabic	763 college students in 82 classes	✓	NA	Arabic translation Students preferred a more positive actual environment.
Afari et al. (in press)	UAE	Arabic	352 college students in 33 classes	✓	Enjoyment Academic efficacy	Arabic translation Use of games promoted a positive classroom environment.
den Brok et al. (2006)	California, USA	English	665 middle-school science students in 11 schools	✓	NA	Girls perceived the environment more favourably.
Martin-Dunlop and Fraser (2008)	California, USA	English	525 female university science students in 27 classes	✓	Attitude	Very large increases in learning environment scores for an innovative course
Ogbuehi and Fraser (2007)	California, USA	English	661 middle-school mathematics students	✓	Two attitude scales	Used 3 WIHIC & 3 CLES scales Innovative teaching strategies promoted task orientation.

Wolf and Fraser (2008)	New York, USA	English	1,434 middle-school science students in 71 classes	✓		Attitudes Achievement	Inquiry-based laboratory activities promoted cohesiveness and were differentially effective for males and females.
Pickett and Fraser (2009)	Florida, USA	English	573 grade 3–5 students	✓		NA	Mentoring program for beginning teachers was evaluated in terms of changes in learning environment in teachers' school classrooms.
Allen and Fraser (2007)	Florida, USA	English Spanish	120 parents and 520 grade 4 and 5 students	✓		Attitudes Achievement	Involved both parents and students Actual-preferred differences were larger for parents than students.
Robinson and Fraser (in press)	Florida, USA	English Spanish	78 parents and 172 kindergarten science students	✓		Achievement Attitudes	Kindergarten level Involved parents Spanish translation Relative to students, parents perceived a more favourable environment but preferred a less favourable environment.
Helding and Fraser (in press)	Florida, USA	English Spanish	924 students in 38 grade 8 and 10 science classes	✓		Attitudes Achievement	Spanish translation Students of NBC teachers had more favourable classroom environment perceptions.

Numerous researchers have incorporated WIHIC scales into specific-purpose questionnaires tailored to the particular contexts and purposes of their studies. For example, working with a sample of 2,638 grade 8 science students from 50 classes in 50 schools in the Limpopo Province of South Africa, Jill Aldridge, Rudiger Laugksch, Mampone Seopa and Barry Fraser (2006b) developed and validated a classroom environment instrument in the Sepedi language for monitoring the implementation of outcomes-based classroom environments. The Outcomes-Based Learning Environment Questionnaire (OBLEQ) contains four scales from the WIHIC, one scale each from the ICEQ and CLES, and a new scale (called Responsibility for Own Learning). As well as validating a widely applicable questionnaire suited for outcomes-based education, the researchers used case studies to support and check the accuracy of profiles of OBLEQ scores for specific classes.

A Greek-language learning environment questionnaire for use in both Greece and Cyprus was developed by Maria Giallousi, Vassilios Gialamas, Nicolas Spyrellis and Evangelia Pavlatou (2010). The three-scale How Chemistry Class is Working (HCCW) questionnaire contains the two WIHIC scales of Involvement and Teacher Support. Data analyses of questionnaire responses from 1,394 Greek students and 225 Cypriot students in grade 10 supported the factor structure of the questionnaire and revealed more positive classroom environment perceptions among Cypriot students than Greek students.

Jeffrey Dorman (2001) combined the seven scales from the WIHIC with three scales from the CLES to form an instrument that was used to investigate associations between student academic efficacy and classroom environment among a sample of 1,055 mathematics students from Australian secondary schools. Overall, this research revealed that classroom environment related positively with academic efficacy. However, commonality analysis showed that the three CLES scales did not contribute much to explaining variance in academic efficacy beyond that attributed to the seven WIHIC scales.

Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI)

Outcomes-focused education has been heralded in many countries as an approach to school reform in which planning, delivery and assessment all focus on the student's outcomes/results from teaching rather than on a syllabus or curriculum. Jill Aldridge and Barry Fraser (2008) conducted a study of an innovative new post-secondary school, whose emphases included an outcomes focus and the use of ICT in programme delivery, during its first year of operation. As part of the formative and summative evaluation of this new school, we designed and used the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI).

The TROFLEI incorporates all of the WIHIC's seven scales (Student Cohesiveness, Teacher Support, Involvement, Task Orientation, Investigation, Cooperation and Equity), but includes three other important scales that were salient in the context of this new school. The Differentiation scale from the ICEQ was included to assess the extent to which teachers cater for students differently according to their abilities, rates of learning and interests. Computer Usage assesses the extent to which students use computers as a tool to communicate with other students and to access information. Young Adult Ethos assesses the extent to which teachers give students responsibility and treat them as young adults.

The TROFLEI has a total of 80 items (with eight items in each of 8 scales) that are responded to using a five-point frequency scale (Almost Never, Seldom, Sometimes, Often and Almost Always). An innovative aspect of the TROFLEI is that it employs a side-by-side response format which enables students to provide their separate perceptions of actual and preferred classroom environment in an economical way.

In collaboration with Jeffrey Dorman, the authors carried out extensive research involving the validation and application of the TROFLEI. Using a large sample of 2,317 students from 166 grade 11 and 12 classes from Western Australia and Tasmania, Jill Aldridge and Barry Fraser (2008, in press) reported strong factorial validity and internal consistency reliability for both the actual and preferred forms of the TROFLEI. As well, the actual form of each scale was capable of differentiating between the perceptions of students in different classrooms.

Aldridge, Dorman and Fraser (2004) used multi-trait–-multi-method modelling with a sub-sample of 1,249 students, of whom 772 were from Western Australia and 477 were from Tasmania (compared with 2,317 students in our entire sample). When the ten TROFLEI scales were used as traits and the actual and preferred forms of the instrument as methods, the results supported the TROFLEI's construct validity and sound psychometric properties, as well as indicating that the actual and preferred forms share a common structure.

When the TROFLEI was used in monitoring and evaluating the success of the new school in promoting outcomes-focused education, changes in students' perceptions of their classroom environments over 4 years supported the efficacy of the school's educational programmes (Aldridge and Fraser 2008, in press). Using structural equation modelling with a sample of 4,146 grade 8–13 students, Dorman and Fraser (2009) used the TROFLEI to establish associations between students' affective outcomes and their classroom environment perceptions. In an investigation of some determinants of classroom environment involving the use of the TROFLEI with 2,317 students, Aldridge and Fraser (2008) reported interesting differences in classroom environment perceptions between males and females and between students enrolled in university-entrance examinations and in wholly school-assessed subjects. With the sample of 4,146 students, Dorman, Aldridge and Fraser (2006) used cluster analysis with TROFLEI responses to identify five relatively homogeneous groups of classroom environments.

Constructivist-Orientated Learning Environment Survey (COLES)

The Constructivist-Orientated Learning Environment Survey (COLES) incorporates numerous scales from the WIHIC into an instrument that is designed to provide feedback as a basis for reflection in teacher action research. In constructing the

COLES, Jill Aldridge, Barry Fraser, Lisa Bell and Jeffrey Dorman (in press) were especially conscious of the omission in all existing classroom environment questionnaire of important aspects related to the assessment of student learning. The COLES incorporates six of the WIHIC's seven scales (namely, Student Cohesiveness, Teacher Support, Involvement, Task Orientation, Cooperation and Equity), while omitting the WIHIC's Investigation scale. Like the TROFLEI, the COLES also includes the scales of Differentiation and Young Adult Ethos. In addition, the COLES includes the Personal Relevance scale from the CLES (the extent to which learning activities are relevant to the student's everyday out-of-school experiences). The two new COLES scales related to assessment are Formative Assessment (the extent to which students feel that the assessment tasks given to them make a positive contribution to their learning) and Assessment Criteria (the extent to which assessment criteria are explicit so that the basis for judgements is clear and public).

For a sample of 2,043 grade 11 and 12 students from 147 classes in nine schools in Western Australia, data analysis supported the sound factorial validity and internal consistency reliability of both actual and preferred versions of the COLES. In addition, each actual form of the COLES was capable of differentiating between the perceptions of students in different classrooms. A noteworthy methodological feature of this study was that the Rasch model was used to convert data collected using a frequency response scale into interval data suitable for parametric analyses. Interestingly, when analyses were performed separately for raw scores and Rasch scores, Aldridge et al. (in press) found that the differences between the validity results (e.g. reliability, discriminant validity and ability to differentiate between classrooms) were negligible.

During action research with teachers, use was made of feedback based on students' responses to both the actual and preferred versions of the COLES, in conjunction with reflective journals, written feedback, discussion at a forum, and teacher interviews. Aldridge et al. (in press) reported the experiences of these teachers concerning the viability of using feedback from the COLES as part of their action research aimed at improving their classroom environments.

Other Classroom Environment Instruments

Many studies have drawn on scales and items in existing classroom environment questionnaires in developing modified instruments which better suit particular research purposes and research contexts. For a study of the classroom environment of Catholic schools, Jeffrey Dorman, Barry Fraser and Campbell McRobbie (1997) developed a 66-item instrument which drew on the CES, CUCEI and ICEQ but made important modifications. The seven scales in this questionnaire (Student Application, Interactions, Cooperation, Task Orientation, Order and Organisation, Individualisation and Teacher Control) were validated using a sample of 2,211 grade 9 and 12 students in 104 classes.

Because a limited number of classroom environment instruments have a reading level suitable for the middle-school level, Becky Sinclair and Barry Fraser (2002) developed a questionnaire based on the MCI and WIHIC for use in teachers' action research attempts to improve their classroom environments in an urban school district. The instrument has the four scales of Cooperation, Teacher Empathy/ Equity, Task Orientation and Involvement, and it was validated with a sample of 745 students in 43 grade 6–8 classes.

In evaluations of computer-assisted learning, Dorit Maor and Barry Fraser (1996) and George Teh and Barry Fraser (1994, 1995) drew on existing scales in developing specific-purpose instruments. Maor and Fraser developed a five-scale classroom environment instrument (assessing Investigation, Open-Endedness, Organisation, Material Environment and Satisfaction) based on the LEI, ICEQ and SLEI and validated it with a sample of 120 grade 11 students in Australia. Teh and Fraser developed a four-scale instrument to assess Gender Equity, Investigation, Innovation and Resource Adequacy, and validated it among 671 high-school geography students in Singapore.

In the first learning environment study worldwide specifically in agricultural science classes, Suleiman Idiris and Barry Fraser (1997) selected and adapted scales from CLES and ICEQ in developing a five-scale instrument to assess Negotiation, Autonomy, Student Centredness, Investigation and Differentiation. This instrument was validated with a sample of 1,175 students in 50 high-school agricultural science classes in eight states of Nigeria.

The Distance Education Learning Environments Survey (DELES) was developed especially to assess post-secondary distance-education learning environments (Walker and Fraser 2005). This six-scale online questionnaire (Instructor Support, Student Interaction and Collaboration, Personal Relevance, Authentic Learning, Active Learning and Student Autonomy) was field tested in the USA with 680 university students. Not only did the DELES exhibit strong factorial validity and internal consistency reliability, but also scores on DELES were related positively to student enjoyment of their distance-education studies.

Based partly on existing instruments, Darrell Fisher and Bruce Waldrip (1997) developed a questionnaire to assess culturally sensitive factors of learning environments. The 40-item Cultural Learning Environment Questionnaire (CLEQ) assesses students' perceptions of Equity, Collaboration, Risk Involvement, Competition, Teacher Authority, Modelling, Congruence and Communication. Administration of the new questionnaire to 3,031 secondary science students in 135 classes in Australia provided support for the internal consistency reliability and factorial validity of the CLEQ. Subsequently, the CLEQ has been successfully cross-validated by Harkirat Dhindsa and Barry Fraser (2004) with 475 teacher trainees at the University of Brunei Darussalam.

Olugbemiro Jegede, Barry Fraser and Darrell Fisher (1995) developed the Distance and Open Learning Environment Scale (DOLES) for use among university students studying by distance education. The DOLES has the five core scales of Student Cohesiveness, Teacher Support, Personal Involvement and Flexibility, Task Orientation and Material Environment, and Home Environment, as well as the two optional scales of Study Centre Environment and Information Technology Resources. Administration of the DOLES to 660 university students provided support for its internal consistency reliability and factor structure.

Instruments for Assessing School Environment

In contrast to work on classroom-level environment, which is the major focus of the present chapter, relatively little research has been directed towards helping teachers assess and improve the environments of their own schools. Earlier instruments include George Stern's (1970) College Characteristics Index (CCI) and Andrew Halpin and Don Croft's (1963) Organizational Climate Description Questionnaire (OCDQ). The Work Environment Scale (WES, Moos 1981) was designed for use in any work milieu rather than for use specifically in schools. To improve the WES's face validity for use in schools, Darrell Fisher and Barry Fraser changed the word 'people' to 'teachers', 'supervisor' to 'senior staff' and 'employee' to 'teacher' (Fisher and Fraser 1983b; Fraser et al. 1988). Of the WES's ten scales, three measure Relationship Dimensions (Involvement, Peer Cohesion, Staff Support), two measure Personal Development Dimensions (Autonomy, Task Orientation) and five measure System Maintenance and System Change Dimensions (Work Pressure, Clarity, Control, Innovation, Physical Comfort). The WES consists of 90 items of True/False response format, with an equal number of items in each scale. Validation data for the WES were generated in a study of 599 teachers in 34 primary and secondary schools in Tasmania (Docker et al. 1989).

The School-Level Environment Questionnaire (SLEQ) was designed especially to assess school teachers' perceptions of psychosocial dimensions of the environment of the school. A review of potential strengths and problems associated with existing school environment instruments suggested that the SLEQ should contain eight scales (Fisher and Fraser 1991; Rentoul and Fraser 1983). Two scales measure Relationship Dimensions (Student Support, Affiliation), one measures the Personal Development Dimension (Professional Interest) and five measure System Maintenance and System Change Dimensions (Staff Freedom, Participatory Decision Making, Innovation, Resource Adequacy and Work Pressure). The SLEQ consists of 56 items, with each of the eight scales being assessed by seven items. Each item is scored on a five-point scale with the responses of Strongly Agree, Agree, Not Sure, Disagree and Strongly Disagree. In addition to an actual form which assesses perceptions of what a school's work environment is actually like, the SLEQ also has a preferred form.

When John Docker, Barry Fraser and Darrell Fisher (1989) used the WES with a sample of 599 teachers in investigating differences between the environment of various school types, reasonable similarity was found for preferred environment scales, but teachers' perceptions of their actual school environments varied markedly in that the climate in primary schools was more favourable than the environment of high schools on most scales. For example, primary schools were viewed as having greater Involvement, Staff Support, Autonomy, Task Orientation, Clarity, Innovation and Physical Comfort and less Work Pressure. Similarly, when Darrell Fisher and Barry Fraser (1991) used the SLEQ in a study of differences between the climates of primary and high schools for a sample of 109 teachers in ten schools, the most striking finding was that the climate in primary schools emerged as more favourable than the environment of high schools on most SLEQ scales.

In a study of the school-level environment of Catholic schools, Jeffrey Dorman, Barry Fraser and Campbell McRobbie (1997) developed a 57-item school environment instrument which includes modified versions of five SLEQ scales (Student Support, Affiliation, Professional Interest, Resource Adequacy and Work Pressure), but which adds the two new scales of Empowerment (the extent to which teachers are empowered and encouraged to be involved in decision-making processes) and Mission Consensus (the extent to which consensus exists within the staff with regard to the overarching goals of the school). This instrument was used in studies of differences in the school environment of Catholic and government schools (Dorman and Fraser 1996) and of associations between school environment and classroom environment (Dorman et al. 1997). For example, for a sample of 208 science and religion teachers from 32 schools, Catholic school teachers saw their schools as more empowering and higher on Mission Consensus than government school teachers.

In South Africa, Jill Aldridge, Rudiger Laugksch and Barry Fraser (2006a) modified the SLEQ to make it suitable for use in the Limpopo Province among teachers who were implementing outcomes-based education (OBE). With a sample of 403 teachers in 54 schools, they validated a questionnaire that combined modified versions of SLEQ scales (namely, Student Support, Collegiality, Innovation, Resource Adequacy and Work Pressure) with two new scales created by the researchers (Parental Involvement and Familiarity with OBE). As well as reporting validity support for this school environment questionnaire, the authors found some differences in the school environments between teachers involved in OBE and teachers who were not.

In Taiwan and based partly on the SLEQ, Shwu-Yong Huang and Barry Fraser (2009) used the Science Teachers' School Environment Questionnaire (STSEQ) to assess the dimensions of Teacher–Student Relations, Collegiality, Principal Leadership, Professional Interest, Gender Equity, Staff Freedom, Innovation, Resources and Equipment, and Work Pressure among 300 female and 518 male science teachers from secondary schools. Gender differences in perceptions were reported for several scales even after controlling for teachers' background and school characteristics.

Using both exploratory and confirmatory factor analysis with data from 1,106 teachers from 59 elementary schools in south-western USA, Bruce Johnson and Joseph Stevens (2001) evolved a 35-item five-scale version of the SLEQ. This refined and more parsimonious version of the SLEQ exhibited psychometric properties that were superior to those for the original 56-item version of the SLEQ.

Different Forms of Learning Environment Instruments

Preferred Forms of Scales

A distinctive feature of most of the instruments in Table 79.1 is that they have, not only a form to measure perceptions of 'actual' or experienced classroom environment, but also another form to measure perceptions of 'preferred' or ideal classroom environment. The preferred form is concerned with goals and value orientations and measures perceptions of the classroom environment ideally liked or preferred. Although item wording is similar for actual and preferred forms, slightly different instructions for answering each are used. For example, an item in the actual form such as ‘There *is* a clear set of rules for students to follow’ would be changed in the preferred form to ‘There *would be* a clear set of rules for students to follow’.

Short Forms of CES, ICEQ and MCI

Although the long forms of classroom environment instruments have been used successfully for a variety of purposes, some researchers and teachers have reported that they would like instruments to take less time to administer and score. Consequently, short forms of the CES, ICEQ and MCI were developed by Barry Fraser (1982) and Barry Fraser and Darrell Fisher (1983a) to satisfy three main criteria. First, the total number of items in each instrument was reduced to approximately 25 to provide greater economy in testing and scoring time. Second, the short forms were designed to be amenable to easy hand scoring. Third, although long forms of instruments might be needed to provide adequate reliability for the assessment of the perceptions of individual students, short forms are likely to have adequate reliability for the many applications which involve averaging the perceptions of students within a class to obtain class means. The development of the short form was based largely on the results of several item analyses performed on data obtained by administering the long forms of each instrument to a large sample. The short form of the ICEQ and the MCI each consists of 25 items divided equally among the five scales comprising the long form. Because the long form of the CES consisted of 90 items, this was reduced to a short version with 24 items divided equally among six of the original nine scales. It is noteworthy that most of the recently developed classroom environment questionnaires (e.g. SLEI, CLES and WIHIC) are relatively short and have scales that each contain 6–8 items.

Personal Forms of Scales

Barry Fraser and Kenneth Tobin (1991) pointed out that there is potentially a major problem with nearly all existing classroom environment instruments when they are used to identify differences between subgroups within a classroom (e.g. males and females) or in the construction of case studies of individual students. The problem is that items are worded in such a way that they elicit an individual student’s perceptions of the class as a whole, as distinct from that student’s perceptions of his/her own role within the classroom. For example, items in the traditional class form might seek students’ opinions about whether ‘the work of the class is difficult’ or whether ‘the teacher is friendly towards the class’. In contrast, a personal form of the same items would seek opinions about whether ‘I find the work of the class difficult’ or whether ‘the teacher is friendly towards me’. Confounding could have arisen in past studies which employed the class form because, for example, males could find a class less difficult than females, yet males and females still could agree when asked for their opinions about the class as a whole. The distinction between personal and class forms is consistent with Robert Stern, Morris Stein and Benjamin Bloom's (1956) terms of 'private' beta press, the idiosyncratic view that each person has of the environment, and 'consensual' beta press, the shared view that members of a group hold of the environment.

When Barry Fraser, Geoffrey Giddings and Campbell McRobbie (1995) developed and validated parallel class and personal forms of both an actual and preferred version of the SLEI, item and factor analyses confirmed that the personal form had a similar factor structure and comparable statistical characteristics (e.g. internal consistency, discriminant validity) to the class form when either the individual student or the class mean was used as the unit of analysis. Also students' scores on the class form were found to be systematically more favourable than their scores on the personal form, perhaps suggesting that students have a more detached view of the environment as it applies to the class as a whole. As hypothesised, gender differences in perceptions were somewhat larger on the personal form than on the class form. Although a study of associations between student outcomes and their perceptions of the science laboratory environment revealed that the magnitudes of associations were comparable for class and personal forms of the SLEI, Barry Fraser and Campbell McRobbie (1995) used commonality analyses to show that each form accounted for appreciable amounts of outcome variance which was independent of that explained by the other form. This finding justifies the decision to evolve separate class and personal forms because they appear to measure different, albeit overlapping, aspects of the science laboratory classroom environment.

Barry Fraser, Darrell Fisher and Campbell McRobbie (1996) administered the WIHIC questionnaire and followed up with interviews with 45 students. Many students reported perceptions from the perspective of the class as a whole that differed from their perceptions of their personal role within the classroom. Underlying many of the responses was the idea that, because the individual student is only part of the class, interactions with an individual student (personal form) are less frequent than the interactions with the class as a whole (class form). Most contemporary learning environment questionnaires, such as the CLES and WIHIC, have items that are written in the personal form.

Research Involving Educational Environment Instruments

Three main types of past research that are considered in detail in this section are (1) associations between student outcomes and environment, (2) use of environment dimensions as criterion variables in the evaluation of educational innovations and (3) teachers' practical attempts to improve their classroom and school environments. In addition, numerous other types of research with learning environment instruments are discussed in somewhat less detail, such as differences between students' and teachers' perceptions of actual and preferred environment; combining quantitative and qualitative methods; school psychology; links between educational environments; cross-national studies; transition between different levels of schooling; and typologies of classroom environments.

Associations Between Student Outcomes and Environment

The strongest tradition in past classroom environment research has involved investigation of associations between students' cognitive and affective learning outcomes and their perceptions of psychosocial characteristics of their classrooms. Numerous research programmes have shown that student perceptions account for appreciable amounts of variance in learning outcomes, often beyond that attributable to background student characteristics. For example, Barry Fraser 's (1994) tabulation of 40 past studies in science education shows that associations between outcome measures and classroom environment perceptions have been replicated for a variety of cognitive and affective outcome measures, a variety of classroom environment instruments and a variety of samples (ranging across numerous countries and grade levels).

For example, using the SLEI, associations with students' cognitive and affective outcomes have been established for a sample of approximately 80 senior high-school chemistry classes in Australia (Fraser and McRobbie 1995; McRobbie and Fraser 1993), 489 senior high-school biology students in Australia (Fisher et al. 1997) and 1,592 grade 10 chemistry students in Singapore (Wong and Fraser 1996). Using an instrument suited for computer-assisted instruction classrooms, George Teh and Barry Fraser (1995) established associations between classroom environment, achievement and attitudes among a sample of 671 high-school geography students in 24 classes in Singapore. Using the QTI, associations between student outcomes and perceived patterns of teacher–student interaction were reported for samples of 489 senior high-school biology students in Australia (Fisher et al. 1995b) and 1,512 primary-school mathematics students in Singapore (Goh et al. 1995).

While many past learning environment studies have employed techniques such as multiple regression analysis, few have used the multi-level analysis in order to take cognisance of the hierarchical nature of classroom settings. Because classroom environment data typically are derived from students in intact classes, they are inherently hierarchical. Ignoring this nested structure can give rise to problems of aggregation bias (within-group homogeneity) and imprecision. Two studies of outcome-environment associations compared the results obtained from multiple regression analysis with those obtained from an analysis involving the hierarchical linear model. The multiple regression analyses were performed separately at the individual student level and the class mean level. In the HLM analyses, the environment variables were investigated at the individual level, and were aggregated at the class level. In Angela Wong, Deidra Young and Barry Fraser's (1997) study involving 1,592 grade 10 students in 56 chemistry classes in Singapore, associations were investigated between three student attitude measures and a modified version of the SLEI. In Swee Chiew Goh, Deidra Young and Barry Fraser's (1995) study with

1,512 grade 5 mathematics students in 39 classes in Singapore, scores on a modified version of the MCI were related to student achievement and attitude. Most of the significant results from the multiple regression analyses were replicated in the HLM analyses, as well as being consistent in direction.

In Turkey, Sibel Telli, Perry den Brok and Jale Cakiroglu (2010) used a translated version of the QTI together with an attitude questionnaire (Fraser 1981a) in an investigation of associations between teacher–student interpersonal behaviour and students' attitudes to science. The large sample consisted of 7,484 grade 9–11 students from 278 classes in 55 public schools in 13 major Turkish cities. The use of multilevel analysis of variance revealed that the influence dimension of the QTI was related to student enjoyment, while proximity was associated with attitudes to inquiry.

Jeffrey Dorman and Barry Fraser (2009) investigated classroom environment, antecedent variables (gender, grade level, and home computer and Internet access) and student affective outcomes using the TROFLEI among 4,146 high-school students from Western Australia and Tasmania. The student outcome measures were attitude to the subject, attitude to computer use and academic efficacy. Confirmatory factor analysis using LISREL supported the ten-scale a priori structure of the TROFLEI. When structural equation modelling using LISREL was used to test a postulated model involving antecedent variables, classroom environment and outcomes: improving classroom environment had the potential to improve student outcomes; antecedents did not have any significant direct effect on outcomes; and academic efficacy mediated the effect of several classroom environment dimensions on attitude to subject and attitude to computer use.

The findings from prior research are highlighted in the results of a meta-analysis conducted by Edward Haertel, Herbert Walberg and Geneva Haertel (1981) and involving 734 correlations from 12 studies involving 823 classes, eight subject areas, 17,805 students and four nations. Learning post-test scores and regression-adjusted gains were found to be consistently and strongly associated with cognitive and affective learning outcomes, although correlations were generally higher in samples of older students and in studies employing collectivities such as classes and schools (in contrast to individual students) as the units of statistical analysis. In particular, better achievement on a variety of outcome measures was found consistently in classes perceived as having greater Cohesiveness, Satisfaction and Goal Direction and less Disorganisation and Friction. Other meta-analyses synthesised by Barry Fraser, Herbert Walberg, Wayne Welch and John Hattie (1987a) provide further evidence supporting the link between educational environments and student outcomes.

Psychosocial learning environment has been incorporated as one factor in Herbert Walberg's (1981) multi-factor psychological model of educational productivity. Based on an economic model of agricultural, industrial and national productivity, this theory holds that learning is a multiplicative, diminishing-returns function of student age, ability and motivation; of quality and quantity of instruction; and of the psychosocial environments of the home, the classroom, the peer group and the mass media. Because the function is multiplicative, it can be argued in principle that any factor at a zero point will result in zero learning; thus either zero motivation or zero time for instruction will result in zero learning. Moreover, it will do less good to raise a factor that already is high than to improve a factor that currently is the main constraint to learning. Empirical probes of the educational productivity model were made by Barry Fraser, Herbert Walberg, Wayne Welch and John Hattie (1987a) by carrying out extensive research syntheses involving the correlations of learning with the factors in the model. Also secondary analyses were conducted with National Assessment of Educational Achievement data by Herbert Walberg (1986) and National Assessment of Educational Progress data by Barry Fraser, Herbert Walberg and Wayne Welch (Fraser et al. 1986; Walberg et al. 1986). Classroom and school environment was found to be a strong predictor of both achievement and attitudes even when a comprehensive set of other factors was held constant.

Table 79.2 in this chapter lists 21 studies that have involved the validation and use of the WIHIC and shows that 13 of these studies included investigation of associations between classroom learning environment and various student outcomes. Overall, this set of studies replicates evidence of associations between student outcomes and the nature of the learning environment for a variety of classroom environment questionnaires, student outcomes, countries, languages, grade levels and subject areas.

Evaluation of Educational Innovations

Classroom environment instruments can be used as a source of process criteria in the evaluation of educational innovations. For example, an evaluation of the Australian Science Education Project (ASEP) revealed that, in comparison with a control group, ASEP students perceived their classrooms as being more satisfying and individualised and having a better material environment (Fraser 1979). The significance of this evaluation is that classroom environment variables differentiated revealingly between curricula, even when various outcome measures showed negligible differences.

By incorporating of a classroom environment instrument within an evaluation of the use of a computerised database, Dorit Maor and Barry Fraser (1996) found that students perceived that their classes became more inquiry-oriented during the use of the innovation. Similarly, in two studies in Singapore, classroom environment measures were used as dependent variables in evaluations of computer-assisted learning by George Teh and Barry Fraser (1994) and computer application courses for adults by Hock Seng Khoo and Barry Fraser (2008).

Rebekah Nix, Barry Fraser and Cynthia Ledbetter (2005) used the CLES in their evaluation of an innovative science teacher development programme (based on the Integrated Science Learning Environment model). Programmes were evaluated in terms of the types of school classroom environments created by these teachers as perceived by their 445 students in 25 classes. For this evaluation, Nix and colleagues evolved an innovative side-by-side response format for the CLES so that students could provide their perceptions of THIS classroom (the students' current class with the teacher who had experienced the professional development) and

OTHER classroom (other classes at the same school taught by different teachers). Students of teachers who had experienced the professional development perceived their classrooms as having appreciably higher levels of the CLES scales of Personal Relevance and Uncertainty relative to the comparison classes.

Catherine Martin-Dunlop and Barry Fraser (2008) evaluated an innovative science course for prospective elementary teachers in a large urban university in California. When learning environment scales selected from the WIHIC and SLEI were administered to 525 females in 27 classes, very large differences were found on all scales (of over 1.5 standard deviations) between students' perceptions of the innovative course and their previous courses.

In a study of 761 high-school biology students in south-eastern USA, Millard Lightburn and Barry Fraser (2007) used the SLEI in an evaluation of the effectiveness of using anthropometric activities. Relative to a comparison group, the anthropometry group had significantly higher scores on some SLEI and attitude scales.

Jill Aldridge and Barry Fraser (2008, in press) used the TROFLEI in monitoring and evaluating the success of an innovative new senior high school in Western Australia in promoting outcomes-focused education. The sample included 449 students in 2001, 626 students in 2002, 471 students in 2003 and 372 students in 2004. Changes in student perceptions of the classroom environments over the 4 years supported the efficacy of the school's educational programmes in that changes were statistically significant and of moderate magnitude (with effect sizes ranging from 0.20 to 0.38 standard deviations) for seven of the ten TROFLEI scales. However, the degree of change in the learning environment differed for different learning areas. Subsequent interviews with administrative staff provided explanations for differences in results between learning areas in terms of whether teachers were proactive in using outcomes-focused learning/teaching principles.

Linda Pickett and Barry Fraser (2009) argued that the litmus test of the success of any teacher professional development programme is the extent of changes in teaching behaviours and ultimately student outcomes in the participating teachers' school classrooms. Consequently, their evaluation of a 2-year mentoring programme in science for beginning elementary-school teachers drew on the field of learning environments in gauging this programme's success in terms of participants' classroom teaching behaviour as assessed by their school students' perceptions of their classroom learning environments. The sample consisted of seven beginning grade 3–5 teachers in south-eastern USA and their 573 elementary-school students. A modified version of the WIHIC was used to assess student perceptions of classroom learning environment as a pre-test and a post-test. Use of MANOVA and effect sizes supported the efficacy of the mentoring programme in terms of some improvements over time in the classroom learning environment, as well as in students' attitudes and achievement.

In New York, Stephen Wolf and Barry Fraser evaluated the effectiveness of using inquiry-based laboratory activities in terms of learning environment, attitudes and achievement. Administration of the WIHIC to 1,434 middle-school science students in 71 classes supported the validity of the WIHIC and analyses for a subsample of students revealed that inquiry instruction promoted more Student

Cohesiveness than non-inquiry instruction (effect size of one-third of a standard deviation). As well inquiry-based instruction was differentially effective for male and female students.

In Singapore, Hock Seng Khoo and Barry Fraser (2008) adapted the WIHIC for use in the evaluation of adult computer application courses. Scales such as Teacher Support were renamed Trainer Support. The sample consisted of 250 working adults (a population seldom researched in past learning environment studies) attending 5 computer education centres in Singapore. Various analyses supported the factorial validity and reliability of the WIHIC when used with this adult sample in the Singaporean context. Generally students perceived their classroom environments positively, with this pattern varying only a little for students of different sexes and ages. However, males perceived significantly more Involvement, whereas females perceived more Equity. Also, whereas males' perceptions of Trainer Support were independent of age; older females had more positive perceptions than younger females.

Teachers' Attempts to Improve Classroom and School Environments

Although much research has been conducted on educational environments, less has been done to help teachers to improve the environments of their own classrooms or schools. However, Barry Fraser (1981b, 1986) has described how feedback information based on student or teacher perceptions can be employed as a basis for reflection upon, discussion of, and systematic attempts to improve, classroom and school environments. Barry Fraser and Darrell Fisher's (1986) case studies of teachers' attempts at improving their classroom environments included a teacher using the CES and following five steps:

1. *Assessment*. All students in the class responded to the preferred form of the CES first, while the actual form was administered in the same time slot 1 week later.
2. *Feedback*. The teacher was provided with feedback information derived from student responses in the form of the profiles representing the class means of students' actual and preferred environment scores. These profiles permitted ready identification of the changes in classroom environment needed to reduce major differences between the nature of the actual environment and the preferred environment as currently perceived by students.
3. *Reflection and discussion*. The teacher engaged in private reflection and informal discussion about the profiles in order to provide a basis for a decision about whether an attempt would be made to change the environment in terms of some of the dimensions. The main criteria used for selection of dimensions for change were, first, that there should exist a sizeable actual-preferred difference on that variable and, second, that the teacher should feel concerned about this difference and want to make an effort to reduce it. These considerations led the teacher to

decide to introduce an intervention aimed at increasing the levels of Teacher Support and Order and Organisation in the class.

4. *Intervention*. The teacher introduced an intervention of approximately 2 months' duration in an attempt to change the classroom environment. This intervention consisted of a variety of strategies, some of which originated during discussions between teachers, and others of which were suggested by examining ideas contained in individual CES items. For example, strategies used to enhance Teacher Support involved the teacher moving around the class more to mix with students, providing assistance to students and talking with them more than previously. Strategies used to increase Order and Organisation involved taking considerable care with the distribution and collection of materials during activities and ensuring that students worked more quietly.
5. *Reassessment*. The student actual form of the scales was re-administered at the end of the intervention to see whether students were perceiving their classroom environments differently from before.

Some change in actual environment occurred during the time of the intervention. When tests of statistical significance were performed, it was found that pre-test–post-test differences were statistically significant only for Teacher Support, Task Orientation and Order and Organisation. These findings are noteworthy because two of the dimensions on which appreciable changes were recorded were those on which the teacher had attempted to promote change. (Note also that there appeared to be a side effect in that the intervention could have resulted in the classroom becoming more task-oriented than the students would have preferred.) Although the second administration of the environment scales marked the end of this teacher's attempt at changing a classroom, it might have been thought of as simply the beginning of another cycle.

Alan Yarrow, Jan Millwater and Barry Fraser (1997) reported a study in which 117 pre-service education teachers were introduced to the field of learning environment through being involved in action research aimed at improving their university teacher education classes and their 117 primary-school classes during teaching practice. The CUCEI was used at the university level and the MCI was used at the primary-school level. Improvements in classroom environment were observed, and the pre-service teachers generally valued both the inclusion of the topic of learning environment in their pre-service programmes and the opportunity to be involved in action research aimed at improving classroom environments.

The methods described above for improving classroom environments have been adapted for use by teachers wishing to improve their school-level environments. Barry Fraser, John Docker and Darrell Fisher (1988) used the WES as part of teacher development activities and reported a case study of a successful school change attempt in a primary school with a staff of 24 teachers. The SLEQ (Fisher and Fraser 1991) was used in similar school improvement studies using the same basic strategy in a primary school with 15 teachers. After an intervention had been implemented for approximately 10 weeks, it was found that sizeable changes had occurred in two of the targeted areas (of about two-thirds of a standard deviation and about half a standard deviation, respectively).

In north Texas, Becky Sinclair and Barry Fraser (2002) collaborated with three urban middle-school teachers of science in action research aimed at changing their classroom environments. They used actual and preferred forms of a questionnaire based on the WIHIC as a source of feedback to guide change attempts. The authors reported that changes occurred in all three case studies on dimensions which the teachers had selected for improvement. Most of these changes were between 0.25 and 0.50 standard deviations. This supports the notion that classroom environments can be improved by teachers who receive feedback, support and training. Furthermore, an important insight gained from this study was that, in classes where males and females have distinctly different perceptions of perceived and preferred classroom environment, environmental change attempts need to involve different interventions for students of different genders.

Two studies in South Africa employed this approach with teachers who used action research in an attempt to improve their classroom learning environments. In Jill Aldridge, Barry Fraser and Sipho Ntuli's (2009) study, 31 in-service teachers undertaking a distance-education programme administered a primary-school version of the WIHIC in the IsiZulu language to 1077 grade 4–7 learners in the KwaZulu-Natal province. Different teachers were able to use feedback from the WIHIC with varying degrees of success in their attempts to improve their classroom environments. In Jill Aldridge, Barry Fraser and Mokgoko Sebela's (2004b) study, a group of 29 mathematics teachers administered the English version of the CLES to 1,864 grade 4–9 learners in 43 classes. During an intervention phase in this study, some teachers were able to increase the constructivist orientation of their classrooms, thus supporting the efficacy of using the CLES to provide feedback to guide change.

Using the 11-scale COLES, Jill Aldridge, Barry Fraser, Lisa Bell and Jeffrey Dorman (in press) explored the viability of teachers using feedback based on their students' actual and preferred learning environment perceptions for reflection in action research aimed at improving their classrooms. Reflective journals, written feedback, forum discussions and teacher interviews also were used to provide feedback. Both actual and preferred forms of the COLES were administered on two occasions – first as a pre-test prior to commencing the action research and as a post-test 6 weeks later after the implementation of classroom strategies aimed at reducing actual-preferred discrepancies on selected COLES scales. Overall, teachers involved found that feedback information based on students' responses to the COLES prompted valuable reflection that led to implementing classroom changes that resulted in improvements in their classroom learning environments.

An interesting feature of Aldrige et al.'s (in press) study was the use of the circular profiles illustrated in Fig. 79.1 as a means of providing each teacher with a comparison of mean actual and preferred responses to the COLES for his/her class. This information was provided, first, only for the pre-test and, later, for both the pre-test and post-test (as shown in Fig. 79.1).

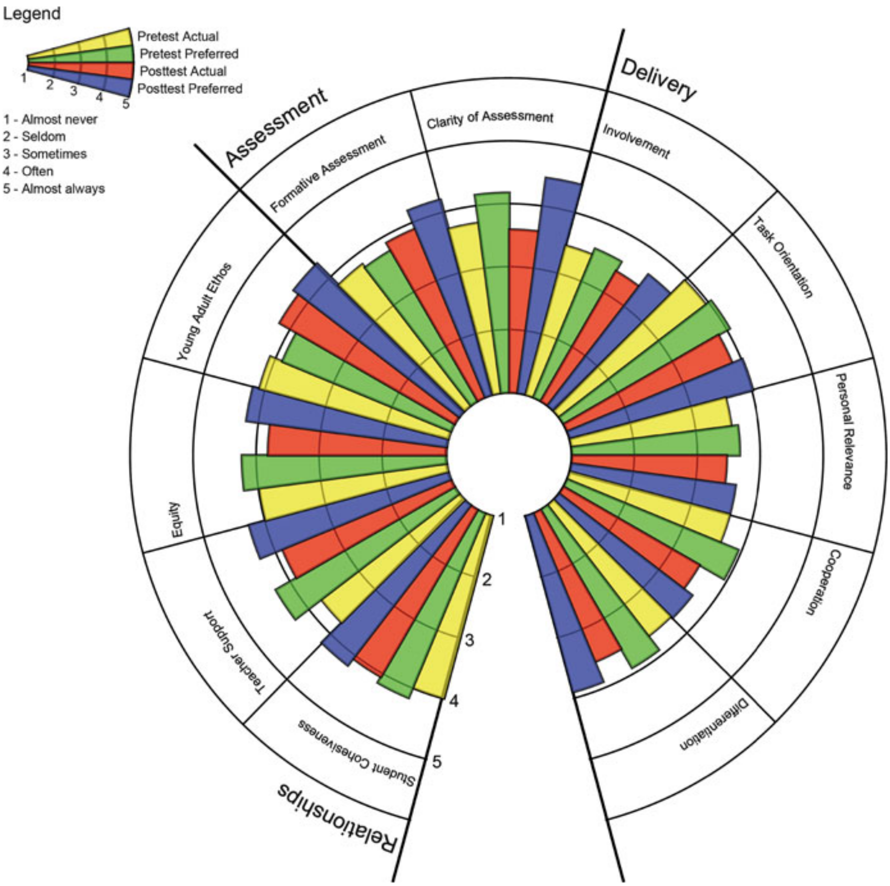

Fig. 79.1 Pre-test and post-test means for actual and preferred versions of 11 COLES scales

Other Applications

Differences Between Students' and Teachers' Perceptions of Actual and Preferred Environment

An investigation of differences between students and teachers in their perceptions of the same actual classroom environment and of differences between the actual environment and that preferred by students or teachers was reported by Darrell Fisher and Barry Fraser (1983a) using the ICEQ with a sample of 116 classes for the comparisons of student actual with student preferred scores and a sub-sample of 56 of the teachers of these classes for contrasting teachers' and students' scores. Students preferred a more positive classroom environment than was actually present for all five ICEQ dimensions. Also, teachers perceived a more positive classroom environment than did their students in the same classrooms on four of the ICEQ's dimensions.

These results replicate patterns emerging in many other studies in school classrooms in the USA (Moos 1979) and Australia (Fraser and McRobbie 1995), as well as in other settings such as hospital wards and work milieus (Moos 1974).

Person–Environment Fit Studies of Whether Students Achieve Better in Their Preferred Environment

Using both actual and preferred forms of educational environment instruments permits exploration of whether students achieve better when there is a higher similarity between the actual classroom environment and that preferred by students. By using a person–environment interaction framework, it is possible to investigate whether student outcomes depend, not only on the nature of the actual classroom environment, but also on the match between students' preferences and the actual environment. Using the CES and ICEQ with a sample of 116 class means, Barry Fraser and Darrell Fisher (1983b, c) predicted post-test achievement and attitudes from pre-test performance, general ability, actual classroom environment variables and variables indicating actual–preferred interaction. Overall, the findings suggested that actual–preferred congruence (or person–environment fit) could be as important as the classroom environment per se in predicting student achievement of important affective and cognitive aims. The practical implication of these findings is that class achievement of certain outcomes might be enhanced by attempting to change the actual classroom environment in ways which make it more congruent with that preferred by the class.

Combining Quantitative and Qualitative Methods

Educational researchers such as Kenneth Tobin and Barry Fraser claim that there are merits in moving beyond choosing between quantitative *or* qualitative methods, to combining quantitative *and* qualitative methods. Some noteworthy progress has been made towards the desirable goal of combining quantitative and qualitative methods within the same study in research on classroom learning environments (Fraser and Tobin 1991; Tobin and Fraser 1998).

A mixed-methods study of learning environments in Taiwan and Australia by Jill Aldridge, Barry Fraser and Iris Huang (1999) has been selected for reprinting in John Cresswell and Vicki Plano Clark's (2007) widely used book *Designing and Conducting Mixed Methods Research* as an exemplary usage of multiple research methods. In this study, the use of the WIHIC questionnaire was combined with classroom observations and interviews with students and teachers. In particular, the authors constructed narratives about what was going on in science classrooms in Taiwan and Australia, as well as identifying emergent themes. Overall, the qualitative information complemented the quantitative information and clarified patterns within the two countries and differences between them.

A team of 13 researchers was involved in over 500 hours of intensive classroom observation of 22 exemplary teachers and a comparison group of non-exemplary teachers (Fraser and Tobin 1989). Although the main data-collection methods were based on interpretive research methods involving classroom observation, interviewing of students and teachers, and the construction of case studies, quantitative information also was obtained from questionnaires assessing student perceptions of classroom psychosocial environment. These instruments furnished a picture of life in exemplary teachers' classrooms as seen through the students' eyes. The study suggested that, first, exemplary and non-exemplary teachers could be differentiated in terms of the psychosocial environments of their classrooms as seen through their students' eyes and, second, that exemplary teachers typically create and maintain environments that are markedly more favourable than those of non-exemplary teachers.

Kenneth Tobin, Jane Kahle and Barry Fraser (1990) reported a study which focused on the goal of higher-level cognitive learning and which involved a team of six researchers intensively investigating the grade 10 science classes of two teachers over a 10-week period. Each class was observed by several researchers, interviewing of students and teachers took place on a daily basis, and students' written work was examined. The study also involved quantitative information from questionnaires assessing students' perceptions of classroom psychosocial environment, which were consistent with the observers' field records of the patterns of learning activities and engagement in each classroom. For example, the high level of personalisation perceived in one teacher's classroom matched the large proportion of time that she spent in small-group activities during which she constantly moved about the classroom interacting with students. The lower level of personalisation perceived in the other teacher's class was associated partly with the larger amount of time that he spent in the whole-class mode and the generally public nature of his interactions with students.

Barry Fraser's (1999) multi-level study of the learning environment of a science class in Australia incorporated a teacher-researcher perspective as well as the perspective of six university-based researchers. Qualitative methods involved several of the researchers visiting this class each time it met over 5 weeks, using student diaries, interviewing the teacher-researcher, students, school administrators and parents, using a video camera, taking field notes and holding team meetings. A quantitative component involving the use of a questionnaire which linked three levels: the class in which the interpretive study was undertaken; selected classes from within the school; and classes distributed throughout the same state. This enabled a judgement to be made about whether this teacher was typical of other teachers at her school, and whether the school was typical of other schools within the state.

School Psychology

Given the school psychologist's/counsellor's changing role, Robert Burden and Barry Fraser consider that the field of psychosocial learning environment furnishes a number of ideas, techniques and research findings which could be valuable in school psychology/counselling. Traditionally, school psychologists have tended to concentrate heavily and sometimes exclusively on their roles in assessing and enhancing academic achievement and other valued learning outcomes. The field of classroom environment provides an opportunity for school psychologists and teachers to become sensitised to subtle but important aspects of classroom life, and to use discrepancies between students' perceptions of actual and preferred environment as a basis to guide improvements in classrooms (Burden and Fraser 1993; Fraser 1987). Similarly, expertise in assessing and improving school environment can be considered important in the work of educational psychologists (Burden and Fraser 1994).

Christopher Sink and Lisa Spencer (2005) advocate accountability for school counsellors and stress the importance of evaluating the efficacy of school counselling programmes, especially in terms of improved classroom environment. These researchers revised and shortened the MCI and validated an 18-item four-scale version with a large sample of 2,835 grade 4–6 students in an urban school district in Washington. Because they found that the revised version of the MCI was psychometrically sound, these researchers recommend its use to school counsellors as an easy-to-use measure that can assist them to gauge whether their classroom work is fostering a higher-level student satisfaction, building more cohesiveness among students, and reducing classroom friction and competitiveness.

Links Between Educational Environments

Although most individual studies of educational environments in the past have tended to focus on a single environment, there is potential in simultaneously considering the links between, and the joint influence of, two or more environments. For example, Kevin Marjoribanks (1991) showed how the environments of the home and school interact to co-determine school achievement, and Rudolf Moos (1991) illustrated the links between school, home and parents' work environments. In order to investigate whether the socio-cultural environment influences Nigerian students' learning of science, Olugbemiro Jegede, Barry Fraser and Peter Okebukola (1994) developed and validated the Socio-Cultural Environment Scale to assess students' perceptions of Authoritarianism, Goal Structure, African World-View, Societal Expectations and Sacredness of Science with 600 senior secondary students. Apparently, students' socio-cultural environment in non-Western societies can create a wedge between what is taught and what is learned.

Several studies have investigated whether the nature of the school-level environment influences or transmits to what goes on in classrooms (i.e. the classroom-level environment). In one such study in South Africa, Jill Aldridge, Barry Fraser and Rudiger Laugksch (2011) used a school environment instrument based on the SLEQ with 50 secondary-school science teachers from 50 different schools, together with a classroom environment questionnaire based on the WIHIC with the 2,638 grade 8 students in the 50 classes of these 50 teachers. Although there emerged a small number of interesting specific relationships (e.g. schools encouraging teachers to be innovative was related to the extent to which students perceived more outcomes-based pedagogy in their classrooms), overall, the school environment did not have a strong influence on what happens in classrooms. Other researchers who have investigated associations between school-level and classroom-level environment include Barry Fraser and A. John Rentoul (1982) and Darrell Fisher, Neville Grady and Barry Fraser (1995a).

When Jeffrey Dorman, Barry Fraser and Campbell McRobbie (1997) administered a classroom environment instrument to 2,211 students in 104 classes and a school environment instrument to the 208 teachers of these classes, only weak associations between classroom environment and school environment were found. Although school rhetoric often would suggest that the school ethos would be transmitted to the classroom level, it appears that classrooms are somewhat insulated from the school as a whole.

Using secondary analysis of a large database from a Statewide Systemic Initiative (SSI) in the USA, Barry Fraser and Jane Kahle (2007) examined the effects of several types of environments on student outcomes. Over 3 years, nearly 7,000 students in 392 middle-school science and mathematics classes in 200 different schools responded to a questionnaire that assesses class, home and peer environments as well as student attitudes. Students also completed an achievement measure. Rasch analyses allowed comparison across student cohorts and across schools. Findings confirmed the importance of extending research on classroom learning environments to include the learning environments of the home and the peer group. Although all three environments accounted for statistically significant amounts of unique variance in student attitudes, only the class environment (defined in terms of the frequency of use of standards-based teaching practices) accounted for statistically significant amounts of unique variance in student achievement scores.

Cross-National Studies

Science education research which crosses national boundaries offers much promise for generating new insights for at least two reasons. First, there usually is greater variation in variables of interest (e.g. teaching methods, student attitudes) in a sample drawn from multiple countries than from a one-country sample. Second, taken-for-granted and familiar educational practices, beliefs and attitudes in one country can be exposed, made ‘strange’ and questioned when research involves two countries.

Jill Aldridge, Barry Fraser and Iris Huang (1999) reported a cross-national learning environment study involving six Australian and seven Taiwanese science education researchers in working together. The WIHIC was administered to 50 junior high-school science classes in each of Taiwan (1,879 students) and Australia (1,081 students). An English version of the questionnaire was translated into Chinese, followed by an independent back translation of the Chinese version into English by team members who were not involved in the original translation. Qualitative data, involving interviews with teachers and students and classroom observations, were collected to complement the quantitative information and to clarify reasons for patterns and differences in the means in each country.

The scales of Involvement and Equity had the largest differences in means between the two countries, with Australian students perceiving each scale more positively than students from Taiwan. Data from the questionnaires were used to guide the collection of qualitative data. Student responses to individual items were used to form an interview schedule which was used to clarify whether items had been interpreted consistently by students and to help to explain differences in questionnaire scale means between countries. Classrooms were selected for observations on the basis of the questionnaire data, and specific scales formed the focus for observations in these classrooms. The qualitative data provided valuable insights into the perceptions of students in each of the countries, helped to explain some of the differences in the means between countries, and highlighted the need for caution when interpreting differences between the questionnaire results from two countries with cultural differences (Aldridge and Fraser 2000). Similar cross-national research involving the use of the CLES in Taiwan and Australia was reported by Jill Aldridge, Barry Fraser, Peter Taylor and Chung-Chi Chen (2000), whereas cross-national research in Indonesia and Australia was reported by Barry Fraser, Jill Aldridge and Gerard Adolphe (2010a).

Transition Between Different Levels of Schooling

There is considerable interest in the effects on early adolescents of the transition from primary school to the larger, less personal environment of the middle school or junior high school at this time of life. Carole Midgley, Lynette Eccles and Harriet Feldlaufer (1991) reported deterioration in the classroom environment when students moved from generally smaller primary schools to larger and departmentally organised lower-secondary schools, perhaps because of less positive student relations with teachers and reduced student opportunities for decision making in the classroom. Peter Ferguson and Barry Fraser's (1998) study of 1,040 students from 47 feeder primary schools and 16 linked high schools in Australia also indicated that students perceived their high-school classroom environments less favourably than their primary-school classroom environments. However, the transition experience was different for boys and girls and for different school size 'pathways' (with students moving from smaller primary schools experiencing greater deterioration in their classroom environments than students moving from larger primary schools).

Typologies of Classroom Environments

The creation and empirical investigation of typologies of classroom learning environments has been pursued in a handful of past studies. Using the CES in the USA among a sample of 200 junior high and high-school classrooms, Rudolf Moos (1978, 1979) identified five clusters that describe five learning environment orientations: control; innovation; affiliation; task completion; and competition.

Using the QTI with samples of students in both the Netherlands and the USA, Mieke Brekelmans, Jack Levy and Rely Rodriguez (1993) identified eight distinct interpersonal profiles: directive; authoritative; tolerant-authoritative; tolerant;

uncertain-tolerant; uncertain-aggressive; repressive; and drudging. Based on a large-scale administration of the QTI to 6,148 grade 8–10 science students from 4 Australian states and their 283 teachers, Tony Rickards, Perry den brok and Darrell Fisher (2005) reported that the 8 types found for Dutch and American teachers only partly applied to the Australian context. Whereas some profiles were less common in Australia, others were more common. Two new types (namely, flexible and cooperative-supportive) were unique to the Australian sample.

Working in Turkey with a Turkish translation of the WIHIC, Perry den Brok, Sibel Telli, Jale Cakiroglu, Ruurd Taconis and Ceren Tekkaya (2010) created learning environment profiles for a sample of 1,474 high-school biology students in 52 classes. The six distinct classroom profiles that emerged were: self-directed learning; task-orientated cooperative learning; mainstream; task-orientated individualised; low-effective learning; and high-effective learning. The most common profile was the mainstream classroom for which all WIHIC scales had medium–high scores.

Based on sample of 4,146 Australian students from 286 grade 8–13 classes, Jeffrey Dorman, Jill Aldridge and Barry Fraser (2006) used the ten-scale TROFLEI to develop a classroom typology. The five relatively homogeneous groups of classes that emerged were: exemplary; safe and conservative; non-technological teacher-centred; contested technological; and contested non-technological. The authors recommended more frequent use of cluster analysis in order to achieve greater parsimony in analysing classroom environment data.

Discussion and Conclusion

The major purpose of this chapter devoted to perceptions of psychosocial characteristics of classroom and school environments has been to make this exciting research tradition in science education more accessible to wider audiences. In its attempt to portray prior work, attention has been given to instruments for assessing classroom and school environments (including some interesting new instruments) and numerous lines of previous research (e.g. associations between outcomes and environment, evaluation of educational innovations, teachers' use of learning environment perceptions in guiding practical attempts to improve their own classrooms and schools, combining quantitative and qualitative methods, incorporating educational environment ideas into school psychology, links between different educational environments, cross-national studies, changes in environment during the transition from primary to high school and typologies of classroom environments.

This chapter has several practical implications for policy-makers and practitioners. First, learning environment assessments should be used in addition to student learning outcome measures to provide information about subtle but important aspects of classroom life. Second, because teachers and students have systematically different perceptions of the same classrooms, student feedback about classrooms should be collected. Third, teachers should strive to create 'productive' classroom learning environments as identified by research. Fourth, in order to improve student outcomes, classroom environments should be changed to make them more similar to those preferred by the students. Fifth, the evaluation of innovations, new curricula and reform efforts should include classroom environment assessments to provide process measures of effectiveness. Sixth, teachers should use assessments of actual and the preferred learning environments to monitor and guide attempts to improve classrooms and schools.

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Chapter 80
Teacher–Students Relationships in the Classroom

Theo Wubbels and Mieke Brekelmans

For both teacher education and professional development programs, information about teacher–students relationships and how interactions shape these relations is important. The way in which a teacher interacts with students is not only a predictor of student achievement, but also it is related to such factors as teacher job satisfaction and teacher burnout as Gabriel Tatar and Moshe Horenczyk (2003) contend. Appropriate teacher–students relationships are important to prevent discipline problems and to foster professional development. Rather than reviewing all the available studies, this chapter discusses typical studies to illustrate the methods used and the type of results found.

A communicative approach is used to analyse teacher–students relationships. We adopt the most comprehensive of three definitions of communicative behaviour. In the first definition, behaviour is called communication only if the same meaning is perceived by the sender and receiver. A second definition considers behaviour to be communicative whenever the sender consciously and purposefully intends to influence someone else. The third definition considers as communication every behaviour that someone displays in the presence of someone else. Adopting this definition, Paul Watzlawick, Janet Beavin and Don Jackson (1967) developed the systems approach to communication that assumes that one cannot not communicate when in the presence of someone else. Our rationale for choosing this perspective is that, whatever someone's intentions are, the other person in the communication will infer meaning from someone's behaviour. For example, if teachers ignore students' questions because they do not hear them, then students might infer that the teacher is too busy, thinks that the students are too dull to understand, or considers the questions to be impertinent. The message that students take from the teacher's inattention can be different from the teacher's intention, because there is no ultimately shared, agreed-upon system for attaching meaning.

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In the systems approach, two levels of extensiveness of interactions are distinguished. Short-term interactions are the exchanges of messages of a few seconds each that consist of one question, one assignment, one response, one gesture, etc. Theo Wubbels, Hans Créton and Anne Holvast (1988) assumed that, in interactions over time, redundancy and repeating patterns evolve. Then interactions on the second level, relatively stable interaction patterns, are seen. According to the systems approach, every form of communication has a content and a relational aspect. The content conveys information or description; the relational aspect carries instructions about how to interpret the content. In a class, the teacher and students relate in ways which are outside the subject matter (content). This chapter focuses on the relational aspect, while not forgetting that every behaviour has at the same time both content and relational meaning.

Gathering Data on Teacher–Students Relationships

Teacher–students relationships and interactions can be studied in several ways. To study short-term interactions, usually observations are employed either with hand or notebook computer scoring. Videotaping improves the quality of this type of data collection because interactions can be reviewed time and time again to get valid and reliable scores. Thus, observer perceptions of these interactions are gathered. For extended patterns over time, these instruments are not economical because they involve a lot of coding and observation time. Instead, other instruments, such as student and teacher questionnaires and interviews, often are used. These instruments map the participants' views of the interactions. It is important to keep in mind that, with these different methods, conceptually different variables are investigated.

Structured Observations

Observation of teacher-students communication in the classroom has a long and firm tradition. Following the development of one of the first instruments for education by Ned Flanders (1970), a plethora of instruments has been documented, such as those by Thomas Good and Jere Brophy (2007). A recent example is an instrument used by Tina Seidel and Manfred Prenzel (2006) in the Third International Mathematics and Science Study. These instruments record observer perceptions of ongoing behaviours of teacher and/or students within the classroom to analyse patterns in the communication. They usually are easy to handle, but extensive training is necessary. Scoring categories can include both verbal elements (question type, source of initiative) and non-verbal elements such as gestures and facial expression. Behaviours are coded using either an event or a time-sampling basis. In an early exemplar instrument, the Science Teaching Observation Schedule (STOS) developed by Maurice Galton and John Eggleston (1979), three main teacher talk categories are distinguished: teacher

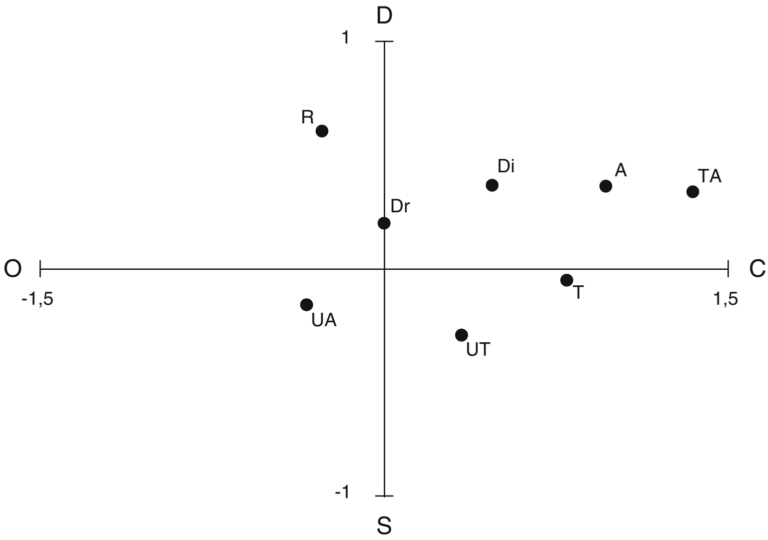

Fig. 80.1 Coordinate system of the Model for Interpersonal Teacher Behaviour and main points of the eight types of patterns of teacher–students relationships: (see section Teaching Styles). *A* authoritative, *Di* directive, *Dr* drudging, *T* tolerant, *R* repressive, *TA* tolerant/authoritative, *UA* uncertain/aggressive, *UT* uncertain/tolerant

asks questions (seven sub-categories including recalling facts); teacher makes statements (four sub-categories including one about problems); and teacher directs students to sources of information (four sub-categories designating the purpose, including one for seeking guidance on experimental procedures). There are two main categories for talk and activity initiated and/or maintained by students: students seek information or consult (four sub-categories designating the purpose, including one for making inferences); and students refer to teachers (four sub-categories designating the purpose, including one for seeking guidance on experimental procedures).

Another observation schedule is based on research on teacher–students relationships by Theo Wubbels et al. (2006). In this system, classroom interaction is analysed on the basis of two dimensions. The *proximity* dimension runs from Cooperation to Opposition and designates the degree of emotional closeness between teacher and students. The *influence* dimension runs from Dominance to Submission and indicates who is directing or controlling the communication and how often. For example, when a teacher is lecturing uninterrupted, his or her behaviour is graphed in the upper right part of the chart in Fig. 80.1. If the students listen in an interested way, this behaviour is shown in the lower right part of Fig. 80.1. The two-dimensional chart can be refined by drawing two extra lines as in Fig. 80.2. This figure (the Model for Interpersonal Teacher Behaviour) provides examples of eight categories of behaviours displayed by teachers: Leadership; Helpful/Friendly; Understanding; Student Responsibility/Freedom; Uncertain; Dissatisfied; Admonishing; and Strict behaviour. Instead of scoring behaviours in the eight categories, they also can be scored on two rating scales (Fig. 80.3).

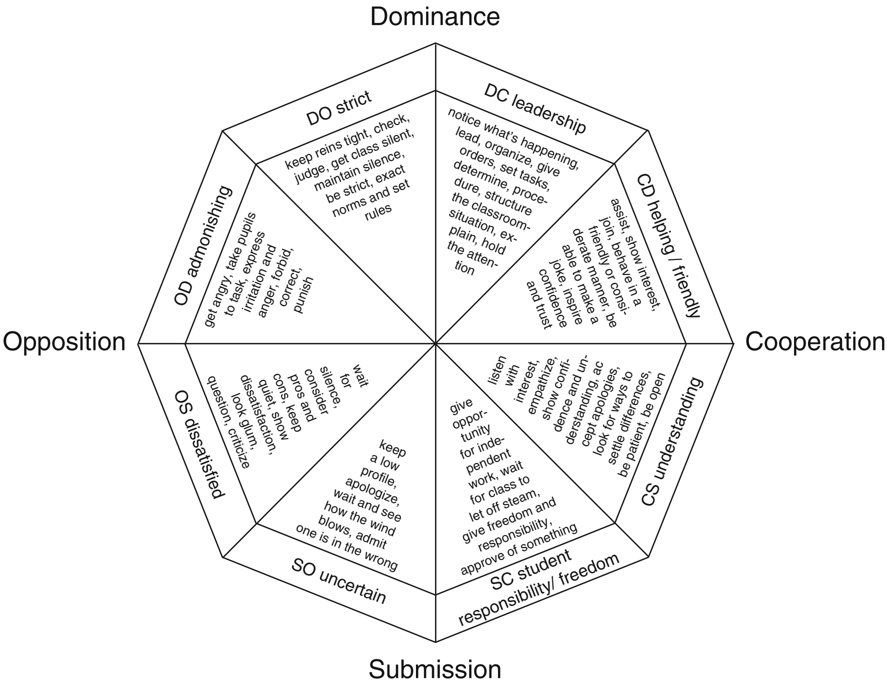

Fig. 80.2 Model for Interpersonal Teacher Behaviour

Dominance (D)		Submission (S)
The teacher determines the students' activities.	5--4--3--2--1	The students can determine their own activities.
Co-operation (C)	5--4--3--2--1	Opposition (O)
The teacher shows approval of the students and their behavior.		The teacher shows disapproval of the students and their behaviour.

Fig. 80.3 Rating scales for observation of students' perceptions

Qualitative Observations

Ethnographic (participant and non-participant) observations often are used to investigate the relational aspect of teacher-students interactions. The type of field notes taken depends on the research question. In the data analysis phase, these observations can be categorised under several headings. Usually, after an initial non-structured phase, observations become more focused on a specific topic. An example of this approach is a study by Wendy Nielsen, Samson Nashon and David Anderson (2009) on students' meta-cognitive engagement in both out-of school and classroom settings, as they participated in an amusement park physics programme. Reflection journals, field notes arising from observations, and formal and informal interviews during post-visit learning activities provided the data corpus on the students' meta-cognitive engagement.

Student and Teacher Questionnaires

In research on classroom social climate, gathering participants' views has a strong tradition. The advantages of this procedure relative to observational measures, as described by Barry Fraser (2007), also hold for measuring teacher–students relationships. Scales that directly or more indirectly give information about teacher–students relationships are contained in the Learning Environment Inventory (LEI) (Goal direction, Formality and Disorganisation), the Classroom Environment Scale (CES) (Teacher Support, Order and Organisation, Task Orientation, Rule Clarity and Teacher Control), the Individualised Classroom Environment Questionnaire (ICEQ) (Participation, Personalisation, Independence) and the What Is Happening In this Class? (WIHIC) questionnaire (Teacher Support, Task Orientation, Involvement, Equity) (see Fraser 2007).

The Questionnaire on Teacher Interaction (QTI) was developed specifically to investigate teacher–students relationships at the pattern level. The QTI, based on the model for interpersonal teacher behaviour, is divided into eight scales which conform to the eight sectors of the model. It was originally developed in the Netherlands, and a 64-item American version was constructed in 1988. The original Dutch version consists of 77 items that are answered on a five-point Likert scale. To make the QTI more accessible to teachers, a short (48-item) version was developed with a hand-scoring procedure. The instrument exists in the following languages, among others: Dutch, English, French, German, Hebrew, Russian, Slovenian, Swedish, Norwegian, Finnish, Spanish, Mandarin Chinese, Singapore Chinese and Indonesian. The QTI was intended for use in secondary education and formed the basis of several new versions, such as a Malay version for primary education by Rowena Scott and Darrell Fisher (2004). Combining elements of the QTI and other communication aspects important for science learning, Hsiao-Ching She and Darrell Fisher (2002) developed the Teacher Communication Behaviour Questionnaire consisting of five scales: Challenging, Encouragement and Praise, Non-Verbal Support, Understanding and Friendly, and Controlling.

With the QTI, student perceptions about the relationship of the teacher with the students as a class, rather than relationships with individual students, have usually been investigated. Perry den Brok, Mieke Brekelmans and Theo Wubbels (2006) used a multi-level design to compare the structure of the traditional QTI and a form developed to measure teachers' relations with individual students. They concluded that, in their relations with individual students, teachers on average were perceived to have more Influence and more Proximity than in their relationship with the class as a whole.

Robert Pianta (2001) developed an instrument that has been used primarily to gather data on teacher perceptions of the relationship with individual children – the Student–Teacher Relationship Scale (STRS). The STRS consists of 28 items rated on a five-point Likert-type scale and contains three sub-scales that measure Conflict, Closeness, and Dependency. The instrument has been widely used and is available in several languages.

Teacher and Student Interviews

Classroom environment questionnaires provide information about students' and teachers' perceptions of teacher–students relationships. In order to understand more fully participants' views, open-ended interviews are helpful because they give participants the opportunity to describe the relationships in their own words. In addition, they have been used in several studies to gather data about underlying beliefs, attitudes, cognitions, intentions, the history of the relationship, interpretations of differences between teachers' and students' perceptions, etc. Finally, interviews also are used as a source for developing questionnaire items.

Teacher–Students Relationships and Student Outcomes

Student outcomes and relations between teachers and their students have been analysed in several studies using typologies of patterns in teacher–students interaction: teaching styles. Non-verbal behaviour and instructional strategies play a role in the relation between teaching styles and student outcomes.

Teaching Styles

The most familiar typologies of teaching styles make the distinction between directive and non-directive communication styles introduced by Neville Bennet (1976). Briefly, open, non-directive teachers emphasise support, innovative instructional procedures and flexible rules. Other studies have extended these typologies to cover more refined categories for communication styles. For example, based on research with the Science Teaching Observation Schedule (STOS), Galton and Eggleston (1979) identified three communication styles in science education. *Problem solvers* are teachers who ask relatively many questions and emphasise problems, hypotheses and experimental procedures. *Informers* are characterised by infrequent use of questions except those demanding recall and the application of facts and principles to problem solving. In the classroom of the third type (the *enquirers*), students initiate interactions more often than in the other classrooms, and they particularly seek information and guidance in designing experimental procedures and in inferring, formulating and testing hypotheses.

A typology of eight categories based on student QTI data from the Netherlands and the USA (see Wubbels et al. 2006) includes three categories that are perceived primarily in the CD quadrant (Fig. 80.1; the Directive, Authoritative and the Tolerant/Authoritative types). Two other types are also very close to this quadrant: the Drudging teacher's behaviour can be located exactly on the influence dimension just above the CO axis; and the Tolerant teacher's behaviour fits just below the proximity axis in the CS quadrant. The three types in the CD quadrant represent more than 50% of the teachers in any sample studied thus far. The three types of teachers in the CD quadrant all show about the same amount of influence. While each one is fairly dominant, they differ in the amount of proximity. The Directive teacher is least cooperative and the Tolerant/Authoritative teacher is most cooperative. The Drudging teacher is a little less dominant and much less cooperative than the other three types. The Tolerant teacher is about as cooperative as the Authoritative teacher, but far less dominant. The Uncertain/Aggressive and Uncertain/Tolerant profiles are most noteworthy for their low scores on the influence dimension. Both are seen as far more submissive than the other types. They differ strikingly from each other on the proximity dimension. The Uncertain/Tolerant teacher resembles the Directive teacher in cooperation, whereas the Uncertain/Aggressive teacher compares to the Repressive teacher in being highly oppositional. Finally, the Repressive teacher is the highest of all on the influence dimension. An Australian study on science teachers by Tony Rickards, Perry den Brok and Darrell Fisher (2005) by and large confirmed this typology. However, two additional types seemed to be present in the Australian context, labelled as Flexible and Cooperative-Supportive. The two new types were characterised by high amounts of helpful/friendly and understanding behaviours, and moderately high amounts of both leadership and student freedom behaviours. Thus, both of these types of teachers are able both to display leadership and to provide opportunities for students to have freedom, depending on the situation.

Teaching Styles and Student Outcomes

Now, how do these communication styles relate to student outcomes? Bennett (1976), in a classical study of teacher communication style and student progress, found that a formal teaching style, with emphasis on external motivation, no choice for students, structured teaching and seatwork with good teacher monitoring and frequent evaluation, was more effective than informal teaching characterised by choice for students, little emphasis on evaluation and control and integration of subjects. Osman Yildirim, Ahmet Acar, Susan Bull and Levent Sevinc (2008) reported that a person-oriented leadership style, more so than a task-oriented style, was favourable for student achievement.

As a historical example of a study in science education using multiple outcome measures, we mention the research with the STOS (Galton and Eggleston 1979). It generally showed that the three teaching styles did not differ in student performance for below-average students. The enquirer style, more so than the other styles, seemed to help low-ability students to enjoy science. The informer style generally was the least effective, particularly for affective outcomes. The problem-solver style was most effective for high-ability students' performance in physics (recall, data manipulation and problem solving). A recent review of research by Tina Seidel and Richard Shavelson (2007) shows that such studies could have overestimated the influence of teaching on student learning.

Several studies of the associations between teacher–students relationships and student outcomes have been carried out with the QTI in science education classrooms. The results of these studies indicate medium to strong relations between student outcomes and student perceptions of teacher–students relationships. The relations are stronger for affective than for cognitive outcomes (Wubbels et al. 2006). The studies show that student perceptions of leadership, helpful/friendly and understanding behaviours are positively related to both student attitudes and student achievement. Uncertain, dissatisfied and admonishing behaviours are negatively related to student outcomes. The direction of relationships between teacher interpersonal behaviour and student outcomes described above confirm earlier findings about the effectiveness of direct instruction strategies summarised by Jere Brophy and Thomas Good (1986). For one aspect of teacher behaviour, the results extend prior research. The results emphasise that disorder, more than openness, seems to be associated with poor student outcomes. Therefore, it is essential that teachers using open teaching styles are able to control student input and procedures in class so as to avoid disorder. Differences in the results found in different countries highlight the need for more research into whether students respond differently to teacher behaviour in different cultures.

It should be kept in mind that the designs in the studies reviewed are correlational and that therefore they do not warrant causal inferences. Certain teacher behaviours can build a working climate in the class and promote student outcomes, whereas other behaviours could hinder student learning. However, it also is plausible that a certain class composition or student characteristics could help to build a positive classroom atmosphere and that this atmosphere gives teachers the possibility to, and even stimulates them to, show behaviours that are positively related to student outcomes. Probably the relationship will be bi-directional, with negative and positive circular processes between teacher behaviour, classroom atmosphere and student outcomes occurring.

Non-verbal Teacher Behaviour

Non-verbal behaviour plays an important role in the development of teacher–students relationships. For example, research by Monica Harris and Robert Rosenthal (2005) indicates that non-verbal aspects of behaviour are important for their interpersonal significance and that these are also related to student outcomes, particularly affective outcomes. Non-verbal behaviours that imply visual contact with the class and emphatic verbal presence are important during whole-class teaching for the rating of teacher behaviour as relatively dominant. When teachers are relatively close to the students, or when they cannot see the students, their behaviour is rated as relatively submissive. The major aspect of non-verbal behaviour for explaining variance in the degree of proximity is the facial expression of the teacher. Further, when teachers raise their voices, this contributes to an oppositional rating of their behaviour.

Instructional Strategies

Because both observed instructional strategies and student perceptions of teacher–students relationships are related to student learning (e.g. Brophy and Good 1986), it is important to ask how much teacher interpersonal behaviour and instructional strategies overlap. The only quantitative measure for this overlap we know of is by Jack Levy, Rely Rodriguez and Theo Wubbels (1992), who found the amount of overlapping variance to be 31%. Statistically significant relations were found mainly for students' perceptions of the influence dimension and instructional strategies. The more the students perceived that teachers behave in dominant ways, the more the teachers displayed effective organisational techniques according to the observer. Further, a teacher who displayed uncertain behaviour, or allowed students a lot of freedom, or often got angry, was not seen by observers to be clear in terms of directions, skill explanation or organisation. The results support the contention that as teachers communicate uncertainty, anger, impatience and dissatisfaction, they display fewer instructional strategies associated with effectiveness.

Correlates of Teacher–Students Relationships

Several variables can be thought to influence the way in which teachers communicate with their students. Most associations with teacher background variables appear to be weak. We will not discuss such weak associations, but focus on variables with stronger associations or variables of potential interest in future research.

Teacher Age and Experience

Throughout their careers, teachers often experience periods of professional growth and decline as described vividly by Christopher Day and his colleagues (2006). These peaks and valleys can affect teacher communication style. Both *experience and age* indeed are important to teacher communication style. Very few studies using other than self-reports are available on teaching careers. An extensive study with the QTI by Mieke Brekelmans, Theo Wubbels and Jan van Tartwijk (2005) indicates that, according to students, changes occur in interpersonal behaviour during the professional career, mainly in behaviour on the influence dimension. This behaviour intensifies during the first 6 years of teaching and stabilises after this point. On the proximity dimension, behaviour basically remains consistent throughout the entire teaching career, but with a slight tendency to weaken after 10 years. The results suggest that teachers with about 6–10 years of experience have the best relationships with their students in terms of promoting student achievement and positive attitudes.

A recent study by Tim Mainhard, Theo Wubbels, Mieke Brekelmans and Perry den Brok (2009) sought to identify the development of teacher–students relationship over a much shorter time span: the first months of the school year. On average, there was a small but persistent decline on the influence and proximity dimensions (i.e. in the quality of the relationship). Thus experience during a school year does not seem to improve teacher–student relationships.

Teacher Cognition

Teacher cognition is often considered an important factor in teacher–students relationships. Teachers' sense of self-efficacy, for example, has generally been found to be a correlate of the quality of teacher–students relationships. The more positively teachers think about their potential to influence student outcomes, the more they achieve a positive classroom atmosphere in their teaching. Similarly, the more teachers think they are able to solve problems in their teaching and the better they think that they can associate with other people, the more they create good student–teacher relationships. For anxiety, the relationship is the other way around as appears from a review by Patricia Jennings and Mark Greenberg (2009). Teachers with a high anxiety level behave in a dogmatic and authoritarian way and lack flexibility. This can produce hostile behaviour in students and make the classroom atmosphere tense and explosive. It is important to keep in mind that, for these kinds of relationships, causality can be in both directions and, therefore, it is most plausible that the relationships are reciprocal. That is, a good classroom atmosphere will give teachers a high regard of their competence to help students to learn and also this self-perception will help teachers to create good relationships.

In teachers' attributions of causes of student performance or problems in classrooms, two distinct patterns can influence their relationships with students. According to Penelope Peterson and Sharon Barger (1985), in the *ego-enhancing pattern*, teachers attribute student success to their own teaching behaviour and student failure to student characteristics such as low ability or low effort. In the other *counter-defensive pattern*, low student outcomes are explained, for example, by a teacher's failure to explain things clearly and students are given credit for their success. Clearly, these two attribution patterns can be the origin of different classroom interaction patterns. In the second pattern more than in the first, the teacher will be inclined to help students and to explain difficult material again, to interact with students in order to explore their mistakes, etc.

Teacher thinking in classroom interaction processes can have a self-reinforcing function. The classical example is the Pygmalion effect described by Robert Rosenthal and Leonore Jacobson (1968). Although the original experiment has been criticised rightly and extensively according to Lee Jussim and Kent Harber (2005), sufficient evidence has been gathered about the (small) influence of teacher expectations on student outcomes. Differential teacher expectations for students go along with differential teacher treatment in terms of such things as praise, questioning, grouping of students and feedback, thus causing unequal opportunities for student learning. Teachers who have low expectations of some students, for example, tend to direct more lower-level questions to these students and more higher-order questions to students with high ability. This could stimulate high-ability students to develop more and more quickly than low-ability students, thus reinforcing teacher perceptions of students and making the prophecy become reality. These results are not by themselves a testimonial of poor teaching. It could be perfectly appropriate for teachers to teach in this way on the basis of valid expectations. In teaching, the validity of expectations, however, should be under continuous scrutiny.

Self-fulfilling prophecies have been studied primarily for teacher expectancies and student outcomes. They are also important in the process of creating a positive classroom climate. An example is the evolution of an undesirable and strongly dependent relationship between teacher and students (Wubbels et al. 1988). When teachers think that students cannot bear much responsibility, they might tend to give limited responsibility to students. For example, they could organise experiences rigidly and give students little opportunity for choice of subject and methods of working. Thus students have to rely on the teacher very much during their activities. This then can stimulate student dependent behaviour and teachers could encourage from students the very behaviour that they expect, thus creating a self-fulfilling prophecy.

Student Gender

Gail Jones and Jack Wheatley (1990) studied differences in teacher–students interactions for male and female students in secondary science classrooms. While they found no differences for several variables, such as the number of student-initiated questions and the number of abstract questions, they found that science teachers praise boys more than girls, put more questions to boys than to girls, and warn boys more often. Although such research has shown that teachers interact differently with boys and girls, Robyn Beaman, Kevin Wheldall and Coral Kempit (2006) contend that this could be more a matter of a small group of troublesome boys receiving extra teacher attention than a general pattern.

In addition to observational studies, research on student perceptions with the QTI, the TCBQ, and the Science Laboratory Environment Inventory has shown consistently that girls perceive the learning environment more positively than boys (She and Fisher 2002). In particular, girls tend to score the behaviour of the same teacher more dominantly and cooperatively than boys do.

Setting

Some studies have investigated differences in teacher–students interactions in different settings in science education. For example, Seidel and Prenzel (2006) investigated interactions in physics lessons for different topics and classroom activities. Teacher–students interactions in these settings appeared to differ very little. Jan van Tartwijk et al. (1998) found that the contribution of teacher–students relationships to the social climate in the science classroom is greater for teacher's behaviour in whole-class settings than during group or laboratory work.

A review by Carol Weinstein (1979) highlighted the influence of physical characteristics of the classroom on teacher–students communication. In whole-class teaching, a short physical distance and eye contact are important for helping teachers to convey to students interest, support and involvement, which are important characteristics of effective teachers. A platform for the teacher to stand on is a physical barrier which can become a psychological barrier. The traditional physics classroom with a demonstration bench could hinder a good relationship and the way in which students sit can obstruct eye contact. It is important to arrange seating in such a way that as few students as possible are sitting behind each other and so that the teacher can move freely between the students.

School Environment

Using the School Level Environment Questionnaire (SLEQ), Darrell Fisher, Barry Fraser and Theo Wubbels (1993) investigated relations between teachers' perceptions of the school environment and teacher–students relationships. Work Pressure, participatory decision making and professional interest appeared to be (weak) negative predictors of student perceptions of the teachers' degree of influence on students and proximity to students. The weak relationship between the SLEQ and QTI scores indicates that a teacher's behaviour in class might have little to do with his/her perception of the school environment. As a result, it seems that teachers believe they have considerable freedom to shape their own classroom regardless of the school atmosphere.

Conclusion

The research reviewed in this chapter supports the importance of teacher–students relationships for creating a classroom atmosphere conducive for science learning. Affective variables seem to be important in a traditional classroom and even more important in a 'constructivist' classroom, where emotion plays a more prominent role. The observation instruments and questionnaires mentioned in this chapter have proven to be helpful for research, as well as for giving teachers feedback about their behaviour. Based on the research reviewed in this chapter, the following recommendations for improving science education can be drawn:

1. In their communication with students, teachers should strive to establish relationships characterised by high degrees of leadership, helpful/friendly and understanding behaviours. In order to succeed, teachers' non-verbal behaviour in whole-class teaching should guarantee good visual contact (e.g. by scanning the class) and teachers should 'hold the floor' verbally. When applying open teaching styles, teachers should avoid the risk of disorderly climates.
2. Teachers can use several student questionnaires (general ones, as well as ones specifically for science education) to gather feedback about their relationships with students, as a basis for reflection and improvement of these relationships. It is important not to rely solely on teacher perceptions because usually the teacher's and students' perceptions differ widely.
3. To improve science teaching through staff development and in-service training programmes, it is more important to change teachers' behaviour and not just attitudes. Attitudes are only a weak predictor of behaviour.
4. Middle-aged teachers should be aware of potential detrimental effects on the classroom atmosphere of lower levels of cooperative teacher behaviour. Beginning science teachers should focus their attention on their leadership behaviour. A good beginning of the school year is essential. Teachers experiencing undesirable classroom situations should focus on their own behaviour as a means for improvement.
5. Teachers should self-analyse their attributions for the success and failure of students as an important means to be attentive to potential interaction patterns that emerge from self-fulfilling prophecies.

Although many issues around teacher–students relationships have been investigated, many others are still open for research. We mention two avenues for future work. First, dynamic systems theories, as described by Esther Thelen and Linda Smith (1994), fits very well with our communicative systems approach and therefore might prove helpful for productively studying the way in which teachers develop positive relationships with their students. For teacher education, this is an important topic of study. Second, we would welcome work on teacher–students relationships in more innovative (e.g. computer-supported) learning environments. A lot of work has been done on student–peer relationships in computer- supported learning environments, but the role of the teacher in such environments has been paid too little attention.

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Chapter 81
Outcomes-Focused Learning Environments

Jill M. Aldridge

Introduction

Gita Steiner-Khamsi (2006), in tracing the history of outcomes-focused education and its adoption around the world by examining legislative benchmarks, found that the overhaul of New Zealand's public sector ended in the State Sector Act of 1988 and the Public Finance Act of 1989, which had important consequences for the education sector by emphasising outcomes-based accountability. At the same time, the UK, under the leadership of Margaret Thatcher, introduced the 1988 Education Act for England and Wales as part of ongoing market-driven reforms. The act introduced a new national curriculum that embodied the language of 'public accountability, effectiveness and market regulation' (Steiner-Khasmi 2006, p. 668).

Outcomes-focused education has been heralded as a means of preparing students for a competitive global economy and workforce in the twenty-first century by the Education Commission of the States (1995) and Sandra Kerka (1998). The outcomes-focused reforms that took place in New Zealand shared features with curriculum reforms that took place in the UK, Australia, Canada, South Africa and, for a brief period, the USA. Countries around the world have been adopting outcomes-focused education as a model for reform in school and post-school education and training systems, including the UK (also known as competency-based education) (e.g. Faris 1998), New Zealand (Bell et al. 1995), Canada (Hopkins 2002), South Africa (Botha 2002) and, to some extent, the USA (also known as performance-based education) (e.g. Evans and King 1994). Common arguments in favour of outcomes-focused education are that it promotes high expectations in students; prepares

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students for life and work in the twenty-first century; fosters more authentic forms of assessment; and encourages decision making regarding curriculum and teaching methods at all levels (Education Commission of the States 1995).

Gita Steiner-Khamsi (2006) describes three stages of adoption of outcomes-focused education around the world. The 'slow growth stage and early adopters' (e.g. New Zealand, UK, Australia, Canada and the USA), the 'explosive growth stage' (several countries in Europe, the most notable being Switzerland, and South Africa in 1998 with its 'Curriculum 2005') and the 'burn out stage and late adopters' (including Central Asian countries such as Kazakhstan, Kyrgyzstan and Mongolia). Roger Dale (2001) describes how countries included in the slow growth stage adopted the New Zealand model in which outcomes-focused education is centred on establishing benchmarks for individual students. Outcomes-focused education, according to Gita Steiner-Khamsi (2006, p. 699), provides a means for measuring teacher performance and monitoring the quality of education more effectively, and 'better responds to the desire for greater public accountability in education'.

Sandra Kerka (1998) and Jim McKernan (1993) acknowledge that the adoption of an outcomes-focused approach to teaching and learning in countries around the world has been surrounded by debate and concerns that encompass both theory and implementation. Colleen Capper (1994) has argued that the approach lacks consideration for social power, Phyllis Schlafly (1993) feels that it is concerned with values and attitudes rather than with objective information, Jonathan Jansen (1998) identifies conceptual confusion, and the risk of 'dumbing-down' the curriculum is identified by Richard Berlach (2004) and Jonathan Jansen (1998). However, the focus for this chapter is not the subjective criticisms associated with outcomes-focused education, but rather how the pedagogy associated with an outcomes-focused philosophy can be implemented and how schools might use information on students' perceptions in monitoring the development of outcomes-focused learning environments.

A review of literature related to outcomes-focused education suggests a dearth of past research associated with its implementation and success at the high school level. Most publications since the turn of the century appear to be centred on theoretical issues concerned with outcomes-focused education (Andrich 2002; Spady 2004; Waghid 2003) and the implementation of outcomes-focused education in South Africa (Aldridge et al. 2006a, b; Botha 2002) and at the post-secondary level (de Jager and Nieuwenhuis 2005; Hoogveld et al. 2005). Therefore, this study of outcomes-focused education and its implementation in an innovative upper-secondary school in Western Australia provides a timely starting point.

There have been numerous interpretations of what constitutes outcomes-focused or outcomes-based education. According to Roy Killen (2001, p. 1), however, outcomes-focused education can be viewed as a theory (or philosophy) of education that is built on a set of assumptions about 'learning, teaching and systemic structures in which these activities take place'. William Spady (1994, 1998) is not the only person to have made a contribution to outcomes-focused education, but generally he is regarded as a world authority on the subject and his publications have provided a description of the theory underpinning outcomes-focused education:

> Outcome-Based Education means clearly focusing and organizing everything in an educational system around what is essential for all students to be able to do successfully at the end of their learning experiences. This means starting with a clear picture of what is important for students to be able to do, then organizing the curriculum, instruction, and assessment to make sure this learning ultimately happens. (Spady 1994, p. 1)

Outcomes-focused education is an approach to planning, delivering and assessing in which one first determines the required results, then identifies the skills and knowledge required to achieve those results. This requires administrators, teachers and students to focus on the desired results of education and what the student can actually do after he or she has been taught. Such a focus requires a shift away from a system in which teachers often taught from a syllabus, irrespective of a student's readiness to learn at that level, to describing the outcomes expected of all students as a basis for: curriculum development; teachers' design of learning programmes; and development of instructional materials and assessment (Spady 1988). Because all curriculum and teaching decisions are based on facilitating the desired student outcomes, the Curriculum Council (2001) and Patrick Griffin and Patricia Smith (1997) recognise that there is an emphasis on catering for student individual differences, interests and learning styles.

Within this broad philosophy of outcomes-focused education, there are two common approaches: the traditional/transitional approach; and the transformational approach (Spady 1993). According to Chris Forlin and Peter Forlin (2002, p. 18) 'traditional outcomes reflect the curriculum based objectives that highlight how successfully students learn'. The traditional/transitional approach favours students' mastery of subject-related content and can be described as involving curriculum-based objectives. It is argued by Sue Willis and Barry Kissane (1995) that The National Curriculum (England and Wales) (which focuses on covering the curriculum within a fixed timeframe) and the 5–14 Development Programme for Scotland (in which movement to the next level is dependent on completion of the previous level) both fall into this category.

Transformational-outcomes education, on the other hand, describes exit outcomes that are cross-curricular and of long-term significance beyond the classroom. Such outcomes, according to Chris Forlin and Peter Forlin (2002, p. 18), are likely to focus on broader issues that are related to a person's life roles, such as being a 'self-directed learner, complex thinker or community contributor', and might include problem solving or working cooperatively. William Spady (1994) is convinced that a truly outcomes-based education includes a curriculum that is designed around complex role performances in real situations with real demands. Sue Willis and Barry Kissane (1995) cite The Common Curriculum and Provincial Standards (Ontario) as an example of a transformational approach to outcomes-based education whose design is based on expected outcomes and which acknowledges that students require differing lengths of time to achieve the outcomes. William Spady (1994) advocates a transformational approach in preference to a traditional/transitional approach as he believes that it leads to more significant learning.

Outcomes-Focused Education in Western Australia

Curriculum reform in Western Australia evolved from the Common and Agreed National Goals of Schooling. In April 1989, State, Territory and Commonwealth Ministers of Education met as the Australian Education Council in Hobart. Ministers made a historic commitment to improving Australian schooling within a framework of national collaboration by reaching agreement to address the areas of common concern embodied in Ten Common and Agreed National Goals for Schooling in Australia that were released as part of the Hobart Declaration (Australian Education Council 1989). In April 1999, State, Territory and Commonwealth Ministers of Education met as the Ministerial Council on Education, Employment, Training and Youth Affairs (MCEETYA 1999) in Adelaide. Ministers endorsed a new set of National Goals for Schooling in the Twenty-First Century known as the Adelaide Declaration.

According to Lesley Parker (2003), outcomes-focused education in Western Australia is part of a package of reforms that was the result of two main drivers. The first concern was that the education system, as it stood, was not sufficiently responsive to students' needs in a time of increasing change (e.g. technological advances, increasing cultural diversity, global environmental issues and changing family and institutional structures). An inclusive curriculum was needed to overcome inequities in the education system. The second driver was public expectation in relation to accountability and standards. The introduction of outcomes-focused education in Western Australia was seen as part of the solution. Whilst the Western Australian model of outcomes-focused education drew on overseas models, it retained unique aspects that address the specific needs of students in Western Australia.

A major review of the curriculum in Western Australia, chaired by Theresa Temby (1995), resulted in the development of the Curriculum Framework (Parker 2003). The review outlined a number of curriculum needs and recommendations. In 1997, a statutory body, the Curriculum Council of Western Australia, was established to work within the Western Australian Curriculum Council Act to oversee the development and implementation of the Curriculum Framework.

The development of the Curriculum Framework was chaired by Lesley Parker and involved a highly collaborative and highly consultative approach that encompassed almost 10,000 teachers, parents, students, academics, curriculum officers and other members of the community (Curriculum Council 2001). The Curriculum Framework provides, for all students, an outline of common learning outcomes upon which schools and teachers can build educational programmes. The Curriculum Framework is outcomes-focused and explicitly advocates a change in teaching and learning approaches. The Curriculum Framework states: 'An outcomes approach means identifying what students should achieve and focusing on ensuring that they do achieve. It means shifting away from an emphasis on what is to be taught and how and when, to an emphasis on what is actually learnt by each student' (Curriculum Council 2001, p. 14).

When developing any curriculum, values play a major role. In the development of the Curriculum Framework, core shared values (in the form of Overarching and

Learning Area Statements) were identified to strengthen and shape it. The Overarching Statement provides the principles that underpin the curriculum, specifies the major ‘knowledge, skills, values and attitudes that all students are expected to acquire’ and provides coherence across all of the curriculum areas through all of the years of study, making for a ‘seamless and integrated curriculum experience for students’ (Parker 2003, p. 25). Each of the eight Learning Area Statements gives support to the Overarching Statement and contributes to the students’ achievement of the Overarching Learning Outcomes (Curriculum Council 2001). The Curriculum Council’s website (www.curriculum.wa.edu.au) provides further information about the philosophy of outcomes-focused education and teaching–learning materials in different learning areas.

The introduction of outcomes-focused education in Western Australia for K–12 began in 1997. In 2004, outcomes-focused teaching became compulsory for K–10 and, in 2005, a Parliamentary Inquiry into changes to the post-compulsory curriculum in Western Australia examined the merits of the proposed changes (in terms of the readiness of the education system and the effects of extending outcomes-focused curriculum, assessment and reporting to upper-secondary education).

My study of outcomes-focused learning environments in Western Australia focuses on the successes and challenges of an innovative new post-compulsory secondary school in creating an outcomes-focused curriculum. Major research aims included the development of a comprehensive and reliable questionnaire to assess students’ perceptions of the outcomes-focused learning environment, evaluating the effectiveness of a new school’s educational programmes in promoting outcomes-focused learning environments, and investigating some of the determinants and effects of outcomes-focused learning environments.

Outcomes-Focused Education and the Field of Learning Environments

Past work on learning environments has furnished numerous conceptual models, research traditions, assessment techniques and research methods. Work on learning environments has been prolific around the world. Numerous specific-purpose instruments have been developed within the field of learning environments and cross-validated and applied for a variety of research purposes. For example, the Science Laboratory Environment Inventory (SLEI) has been used in five countries by Barry Fraser et al. (1995), in the USA by Millard Lightburn and Barry Fraser (2007) and in Singapore by Angela Wong and Barry Fraser (1996). The Constructivist Learning Environment Survey (CLES), developed by Peter Taylor and his colleagues (1997), has been used in Korea by Heui-Baik Kim and her colleagues (1999), in the USA by Rebekah Nix and her colleagues (2005) and Howard Spinner and Barry Fraser (2005) and in Taiwan by Jill Aldridge et al. (2000). The What Is Happening In this Class? (WIHIC) has been used and cross- validated in three countries by Jeffrey Dorman (2003), in Australia and Taiwan by Jill Aldridge et al. (1999), in Singapore by Yan Huay Chionh and Barry Fraser (2009) and in the USA by Catherine Martin-Dunlop and Barry Fraser (2008), Philip Ogbuehi and Barry Fraser (2007) and Stephen Wolf and Barry Fraser (2008).

The many classroom environment studies conducted around the world with a variety of purposes over the last 30 years are reviewed by Darrell Fisher and Myint Swe Khine (2006), Barry Fraser (1998, 2007), and Swee Chiew Goh and Myint Swe Khine (2002). One of the major applications of learning questionnaires in past research has been as a source of process criteria of effectiveness in the evaluation of educational innovations. For example, the use of learning environment criteria has illuminated the impact of new educational programmes or approaches in studies of computer-assisted learning by Dorit Maor and Barry Fraser (1996) and George Teh and Barry Fraser (1994), computer courses for adults by Hock Seng Khoo and Barry Fraser (2008), inquiry-based science instruction for middle-school students by Stephen Wolf and Barry Fraser (2008) and an innovative science course for prospective elementary students by Catherine Martin-Dunlop and Barry Fraser (2008).

In other research, links between different educational environments (e.g. the home and school) have also been explored by Jeffrey Dorman et al. (1997), Barry Fraser and Jane Kahle (2007), Kevin Marjoribanks (1991) and Rudolph Moos (1991). Cross-national studies have also been conducted to explore educational practices, beliefs and attitudes that differ between countries, and which could lead to suggestions for improving educational practices or identifying unique cultural characteristics of each location (Jill Aldridge and Barry Fraser 2000; Jill Aldridge et al. 1999, 2000). In an interesting application of learning environment ideas, Peter Ferguson and Barry Fraser (1998) investigated changes in classroom learning environment across the transition from primary to secondary school.

In the past, researchers have investigated various determinants of classroom environment. For example, studies undertaken by Choon Lang Quek and her colleagues (2005a, b) and George Teh and Barry Fraser (1995) have revealed that, relative to males, females tend to perceive the same classroom environments more favourably. Studies that have investigated both students' and teachers' perceptions of both actual and preferred classroom environment have revealed that, first, teachers tend to perceive the same classroom environments more favourably than their students and, second, both teachers and students prefer a more favourable classroom environment than the one perceived to be actually present (Byrne et al. 1986; Fisher and Fraser 1983). Grade-level and ethnic differences in classroom environment perceptions have been reported by Gloria Castillo et al. (2006).

A review of learning environment literature indicates that only three studies have attempted to examine the learning environments of outcomes-focused classrooms: a study conducted in Western Australia by Jill Aldridge and Barry Fraser (2008); a study of school-level environments in South Africa by Jill Aldridge et al. (2006a); and Jill Aldridge et al.'s (2006b) study of classroom-level environment in South Africa. The following section describes a questionnaire developed to assess and monitor outcomes-focused learning environments.

Development of a Questionnaire to Monitor Outcomes-Focused Learning Environments

This section describes the development and validation of a widely applicable and distinctive questionnaire (the TROFLEI) for assessing students' perceptions of their classroom learning environments in outcomes-focused learning settings. The development of this questionnaire involved a number of steps. In the first place, a literature review helped to identify aspects of the learning environment that could be considered important in classrooms aiming to employ an outcomes focus. Next, teachers and administrators were also involved in the selection of relevant scales. In the next step, suitable scales and items were adopted and adapted from already existing and widely used general classroom environment questionnaires, especially the What Is Happening In this Class? questionnaire (Aldridge and Fraser 2000). During this step, the selection of different scales was also made to ensure coverage of Rudolf Moos' (1974) scheme which was developed for classifying human environments into three dimensions (relationship, personal development, and system maintenance and change) to enable the classification and sorting of various components of any human environment. The instrument was then field tested with a large and heterogeneous sample of students. Finally, various statistical analyses were conducted with data from student responses (e.g. factor analysis and item analysis) to refine the scales and furnish validity and reliability information.

Identifying Important Aspects of the Learning Environment

As a first step, it was important to identify principles that could be considered important in a learning environment that enabled an outcomes focus, and then to delineate dimensions that could be used as a basis for developing specific scales that would give an indication of whether these principles were indeed being achieved.

Because an important principle related to outcomes-focused education is acknowledgement that students differ in terms of their abilities, rates of learning and interests (Griffin and Smith 1997; Spady 1993), teachers need to provide students with learning experiences that cater for the diversity of students in a classroom. With this in mind, the *Differentiation* scale was selected to assess the extent to which students perceive that teachers cater differently for students based on students' capabilities and interests.

Another important principle espoused by William Spady (1994) and Roy Killen (2001) is that students need to have goals, both short-term and long-term, to provide them with motivation and purpose. If these goals are clear and relevant, then students are more likely to engage in learning. Coupled with the need to have meaningful goals is the need to have clear expectations and frequent feedback and reinforcement to ensure that students' time-on-task is optimised. To assess the extent to which students' perceive that it is important to complete activities and understand the goals of the subject, the *Task Orientation* scale was selected.

Research has established that if students are actively involved in learning activities, then it is likely that learning will be more meaningful to students. According to the Curriculum Council (2001, p. 34) 'students should be encouraged to think of learning as an active process on their part, involving a conscious intention to make sense of new ideas or experiences and improve their own knowledge and capabilities, rather than simply to reproduce or remember'. To examine the extent to which this is happening in the learning environment, the two important scales of Involvement and Investigation were selected.

Involvement focuses the extent to which students feel that they have opportunities to participate in discussions and have attentive interest in what is happening in the classroom. According to Peter Taylor and Mark Cambell-Williams (1993), language plays an important part in helping students to understand what they are learning. The selection of this scale was made on the assumption that giving students opportunities to participate in classroom discussions and to negotiate ideas and understandings with peers, rather than listening passively, are important aspects of the learning process.

Investigation involves the extent to which emphasis is placed on the skills and process of inquiry and their use in problem solving and investigation. This scale assumes that, in order for learning to be meaningful, teachers should create appropriate conditions to facilitate students' active engagement in their learning (Spady 1994). In this way, according to the Curriculum Council (2001), students have the opportunity to carry out relevant actions and to reflect upon these to help them to make sense of the results of those actions.

In developing this questionnaire, a situation in which teachers encourage a cooperative learning environment, rather than a competitive one, was considered desirable. Whilst it is acknowledged that students should be given opportunities to work as individuals, it is equally important that they work together collaboratively. According to David Johnson and his colleagues (2007), learning experiences should involve opportunities for students to cooperate with and learn from each other. It was with this in mind that the *Cooperation* scale was selected to assess the extent to which students cooperate with one another in a collaborative atmosphere.

It was considered important that the learning environment created by teachers is supportive to students, providing the intellectual, social and physical conditions for effective learning. Students are more likely to do well in their learning if they feel accepted and do not experience harassment and prejudice from either the teacher or their peers. Two scales were selected for assessing the extent to which students feel that their learning environment is conducive to learning, namely, Student Cohesiveness and Teacher Support.

Student Cohesiveness assesses the extent to which students know, help and are supportive of one another. To make sure that the environment is supportive of student learning, teachers need to create policies and practices that help students to feel that they are accepted and supported by their peers (Curriculum Council 2001). A supportive environment allows students to make mistakes without running the risk of being ridiculed. Social acceptance by peers and the need to have friends are important aspects that can affect students' learning.

Teacher Support assesses the extent to which the teacher helps, befriends, trusts and is interested in students. The teacher's relationship with his or her students is a pivotal aspect of any learning environment, which can lead the student to love or hate a subject, and to be inspired or turned away from learning. The supportiveness of a teacher helps to give students the courage and confidence needed to tackle new problems, take risks in their learning, and work on and complete challenging tasks. If students consider a teacher to be approachable and interested in them, then they are more likely to seek the teacher's help if there is a problem with their work. Daphne Hijzen and her colleagues (2007) identified that the teacher's relationship with his or her students, in many ways, is integral to a student's success and to creating a cooperative learning environment. It was with this in mind that the Teacher Support scale was selected.

An outcomes-focused learning environment, according to William Spady, also requires the teacher to provide opportunities for all of the students in the class (Spady 1994). The *Equity* scale assesses the extent to which students' perceive that the teacher treats them in a way that encourages and includes them as much as their peers. This scale gives teachers an indication of whether students perceive that they are being treated fairly by the teacher.

To examine whether students feel that they are encouraged to be responsible for their own learning, a scale called *Young Adult Ethos* was developed to assess whether students feel that teachers give them responsibility and treat them as young adults.

Finally, because it was considered possible that ICT could help teachers to enable a more outcomes-focused learning environment, it was considered important to assess the extent to which teachers designed their lessons in a way that enabled students to make use of this technology (e.g. as a tool to communicate with others or to access information). The *Computer Usage* scale was therefore designed to assess the extent to which students perceive that they are given the opportunity to use computers in different ways (e.g. emails, discussion boards).

Although it is acknowledged that a questionnaire comprising ten scales cannot assess every aspect of the learning environment, the selected scales are all considered to be especially relevant to outcomes-focused learning environments. Importantly, Jill Aldridge et al. (1999) have shown that many of these scales were predictors of student outcomes in past research.

For each of the ten scales, Table 81.1 provides a scale definition, its alpha reliability, a sample item, and its relevance to the Curriculum Council's (2001) teaching and learning principles.

The new instrument, named the Technology-Rich Outcomes Focused Learning Environment Instrument (TROFLEI) contains 80 items with eight items belonging to each of ten scales. Items are responded to on a five-point frequency scale with the alternatives of Almost Never, Seldom, Sometimes, Often and Almost Always. To provide contextual cues and to minimise confusion among students, Jill Aldridge and colleagues (2000) grouped together in blocks all of the items that belong to the same scale instead of arranging them randomly or cyclically. To give students confidence when completing the questionnaire, the scales were sequenced so that more familiar issues (such as Student Cohesiveness) were placed before less familiar issues (such as Involvement).

Table 81.1 Internal consistency reliability (Cronbach alpha coefficient) for the actual version with the individual as the unit of analysis, scale description and sample item for each TROFLEI scale and its relevance to the principles of outcomes-focused education

Scale	Alpha Reliability	Description	Sample Item	Relevance to Outcomes-Focused Approach According to Curriculum Council (2001)
		The extent to which …		
Student Cohesiveness	0.87	Students know, help and are supportive of one another.	Students in this class like me.	The learning environment should provide a cooperative atmosphere in which students feel that they are supported by their peers.
Teacher Support	0.92	The teacher helps, befriends, trusts and is interested in students.	The teacher is interested in my problems.	To ensure that the atmosphere is conducive to effective learning, teachers should provide a supportive learning environment in which they foster a sense of trust and belonging.
Involvement	0.90	Students have attentive interest, participate in discussions, do additional work and enjoy the class.	I explain my ideas to other students.	Learning experiences should encourage students to be active participants in the learning process.
Investigation	0.92	Emphasis is placed on the skills and processes of inquiry and their use in problem solving and investigation.	I find out answers to questions by doing investigations.	Learning experiences should provide students with opportunities to engage fully with concepts that they are to develop.
Task Orientation	0.88	It is important to complete activities planned and to stay on the subject matter.	I know the goals for this class.	Purposeful learning can be enhanced by making clear the long-term outcomes expected to result from students' engagement with the learning experiences provided.
Cooperation	0.91	Students cooperate rather than compete with one another on learning tasks.	I work with other students on projects in this class.	Learning experiences should provide students with opportunities to work collaboratively with others to and contribute in various ways.
Equity	0.94	Students are treated equally by the teacher.	The teacher gives as much attention to my questions as to other students' questions.	Education is for all students – the learning environment should provide an atmosphere in which all students feel that they are treated in a way that is fair.

Differentiation	0.85	Teachers cater for students differently on the basis of ability, rates of learning and interests.	I work at my own speed.	Learning experiences should accommodate differences between students by providing time and conditions that acknowledge that students bring with them a range of experiences and develop at different rates.
Computer usage	0.88	Students use their computers as a tool to communicate with others and to access information.	I use the computer to obtain information from the Internet.	Learning experiences should provide students with the opportunity to build motivation and confidence to develop and use a range of technological solutions to meet their needs.
Young Adult Ethos	0.93	Teachers give students responsibility and treat them as young adults.	I am expected to think for myself.	Classroom practices should encourage students to take responsibility for their own learning.

The response alternatives for each TROFLEI item are Almost Never, Seldom, Sometimes, Often and Almost Always

	ACTUAL					PREFERRED				
Equity	Almost Never	Seldom	Some times	Often	Almost Always	Almost Never	Seldom	Some times	Often	Almost Always
50. I get the same amount of help from the teacher as do other students.	1	2	3	4	5	1	2	3	4	5

Fig. 81.1 Illustration of side-by-side response format for actual and preferred TROFLEI items

In past learning environment research, a parallel *preferred* version of a questionnaire has often been used in conjunction with the *actual* form (Fraser 2007). Whilst the actual version of a questionnaire assesses students' perceptions of the learning environment created, the preferred version is designed to allow teachers or researchers to examine how students would prefer the learning environment to be. In developing and using the TROFLEI, both the preferred and actual forms were included. Historically, in studies in which both the actual and preferred classroom environment are assessed, researchers have administered separate actual and preferred versions of questionnaires. However, to provide a more economical format in our research, the TROFLEI pioneered the inclusion of two adjacent response scales on the one page (one to record what students perceived as actually happening in their class and the other to record what students would prefer to happen in their class). This side-by-side layout of the responses for actual and preferred forms of the TROFLEI is illustrated in Fig. 81.1. A copy of the TROFLEI can be found in Jill Aldridge and Barry Fraser's (2008) book, *Outcomes-Focused Learning Environments: Determinants and Effects.*

Validity and Reliability of TROFLEI

To provide a large and more generalisable sample for validating the TROFLEI, the sample included government coeducational schools from two Australian states, Tasmania and Western Australia. It was considered prudent to include schools from Tasmania as this state was introducing outcomes-focused education state-wide at the senior-school level. This sample consisted of 2,317 students in 166 classes in 10 senior colleges (i.e. schools catering for grades 11 and 12 only). The sample was selected to be representative of students in these two states, and was made up of 45.1% of students from examination-oriented courses and 54.9% of students from wholly school-assessed courses.

Principal axis factor analysis with varimax rotation was used to extract a factor structure for the TROFLEI to check against the a priori ten-scale structure. A separate factor analysis was conducted for actual and preferred data. Prior to conducting the factor analysis, the assumptions which underlie the application of the principal axis factor analysis, including the proportion of sampling units to variables and the sample being selected on the basis of representation, were considered.

Factor analysis confirmed a slightly refined structure for the actual and preferred forms of the TROFLEI comprising 77 items in the same ten scales. The two criteria used for retaining any item were that it must have a factor loading of at least 0.40 on its own scale and less than 0.40 on each of the other nine TROFLEI scales. Items 57, 58 and 61 from the Differentiation scales were omitted as they did not load 0.40 or above on their own or on any other scale. All of the remaining 77 TROFLEI items had a loading of at least 0.40 on their a priori scale and no other scale for both the actual and preferred versions. For the actual version, the percentage of variance varied from 3.75% to 6.99% for different scales, with the total variance accounted for being 58.03%. For the preferred version, the percentage of variance ranged from 4.03% to 7.96% for different scales, with a total variance accounted for being 64.97%. These results support those found by Aldridge, Dorman and Fraser (2004) in their use of multi-trait–multi-method modelling to validate the actual and preferred forms of the TROFLEI.

For the refined 77-item version of the TROFLEI, three further indices of scale reliability and validity were generated separately for the actual and preferred versions. A convenient discriminant validity index (namely, the mean correlation of a scale with other scales) was used as evidence that each TROFLEI scale measures a separate dimension that is distinct from the other scales in this questionnaire. Analysis of variance (ANOVA) was used to check the ability of each scale in the TROFLEI's actual form to differentiate between the perceptions of students in different classrooms.

The internal consistency of each TROFLEI scale was established using Cronbach's alpha coefficient for two units of analysis (the individual student and the class mean). Using the individual as the unit of analysis, scale reliability estimates ranged from 0.85 to 0.94 for the actual form and from 0.86 to 0.95 for the preferred form. Generally, reliability figures were even higher with the class mean as the unit of analysis (ranging from 0.90 to 0.97 for the actual form and from 0.91 to 0.97 for the preferred form). These internal consistency indices are comparable to those in past studies that have used the WIHIC such as Jill Aldridge and Barry Fraser's (2000) study in Australia and Taiwan, Yan Huay Chionh and Barry Fraser's (2009) study in Singapore and Stephen Wolf and Barry Fraser's (2008) study in the USA.

Using the individual as the unit of analysis, the discriminant validity results (mean correlation of a scale with other scales) for the ten scales of the TROFLEI ranged from 0.15 to 0.39 for the actual form and from 0.15 and 0.48 for the preferred form with the student as the unit of analysis. With the class mean as the unit of analysis, scale discriminant validity ranged from 0.20 to 0.48 for the actual form and from 0.19 to 0.52 for the preferred form. These results suggest that raw scores on the TROFLEI assess distinct but somewhat overlapping aspects of learning environment. However, the factor analysis results support the independence of factor scores on the ten scales.

It was important to determine the degree to which the actual form of the TROFLEI is capable of differentiating between the perceptions of students in different classes. To do this, a one-way analysis of variance (ANOVA), with class membership as the independent variable ($N = 166$), was computed for each TROFLEI scale. The proportion of variance accounted for by class membership was calculated using the eta^2 statistic (the ratio of 'between' to 'total' sums of squares). The ANOVA results revealed that all ten TROFLEI scales differentiated significantly between classes ($p < 0.01$). That is, students within the same class perceived the environment in a relatively similar manner, while the within-class mean perceptions of the students varied between classes. The eta^2 statistic (an estimate of the strength of association between class membership and the dependent variable) ranged from 0.07 to 0.22 for different TROFLEI scales.

Using the TROFLEI to Monitor the Development of an Outcomes-Focused Learning Environment

When one senior school in Western Australia worked to establish an outcomes focus to learning, an important part of the evolution was the monitoring of the outcomes achieved. The principal had 'unyielding faith in teachers to do the right thing by students' but was not sure that they were always as objective as they could be. In his opinion, if teachers implement ideas or changes, then they quickly develop strong ownership of the programmes and are often reluctant to question their effectiveness. To this end, he felt that there was a need to be able to step back and evaluate students' outcomes and programmes in an objective and analytical manner. To do this, the school relied on feedback from various data sources including students' achievement results, parent feedback, teacher feedback and student feedback. The TROFLEI was used as part of the schools monitoring process that could be used to help to evaluate the success of the programmes.

The successful adoption of an outcomes focus required involvement at all levels of the school's operation (individual, classroom and whole-school). The data generated using the TOSRA was used as a source of data at each of these levels to provide evidence upon which judgements could be made that would help to decide future actions.

The TROFLEI has been used at the school for the past 6 years to help to monitor the learning environment, but this chapter reports only the first 4 years. Data collected using the TROFLEI over 4 years (449 students in 2001, 626 students in 2002, 471 students in 2003 and 372 students in 2004) were used at the whole-school, learning area and individual teacher levels. At the whole-school level, administrators used the information to gauge the school's overall performance in terms of providing a learning environment that is likely to enable an outcomes focus. At this level, the results were used alongside other data to guide decision making in terms of the types of professional development that would be most helpful to teachers and to provide a focus for whole-school improvement initiatives. Based on these decisions, reference groups, made up of teachers, were formed to help to guide decision making about how changes might be realised and the types of professional development sessions that would help the teachers.

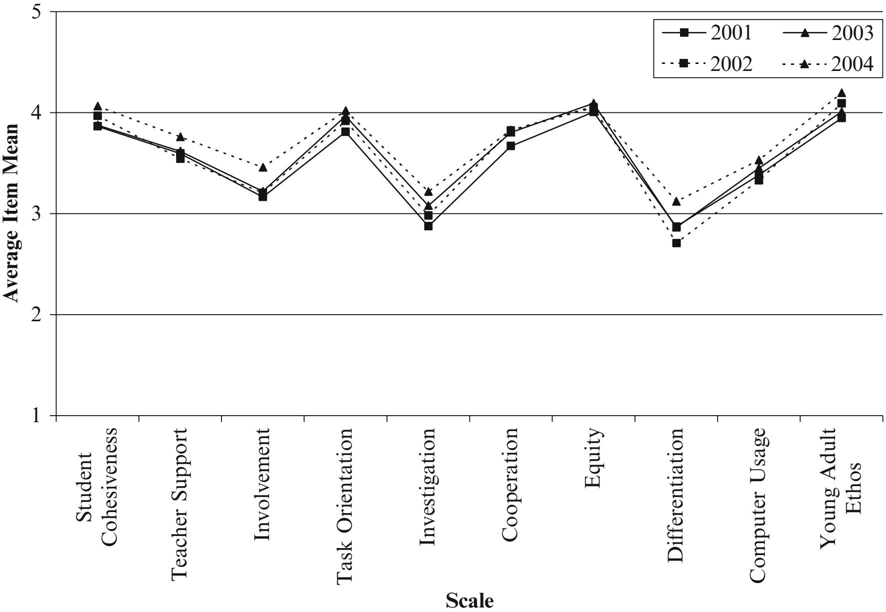

Fig. 81.2 Average item mean for actual and preferred scores on the TROFLEI scales for students enrolled in 2001, 2002, 2003 and 2004

At the learning area level, the results proved to be useful in terms of opening dialogue and generating discussion between teachers. In many cases, these discussions encouraged collaboration between teachers in the same learning area in a bid to improve the outcomes-focused learning environment. Finally, and possibly most importantly, teachers were able to use feedback information about his/her classes to guide the implementation of classroom strategies that are likely to enhance one or more elements of the classroom environment. Using an action research process, individuals were encouraged to change aspects of their learning environment to provide a more outcomes-focused approach. The success of encouraging each teacher to 'tweak' their own learning environment, in addition to supportive professional development that focused on one or two aspects deemed important was monitored over 4 years. For example, in 2004, the scale Differentiation (which assesses the extent to which students perceive that teachers cater for students differently based on students' capabilities and interests) was focused on. A coordinator was appointed to assist teachers to design strategies and incorporate ideas into their teaching. As indicated in Fig. 81.2, when compared to other years, the school and individual teachers had succeeded in making their learning environments more outcomes focused in this respect.

Figure 81.2 provides a graphical representation of students' perception over the 4 years. The results indicate that there were statistically significant differences in students' perceptions of classroom environment over the years from 2001 to 2004 for all TROFLEI scales with the exception of the Equity scale.

Tukey's HSD multiple comparison procedure revealed that there were statistically significant changes for four learning environment scales between 2001 and 2002; for one scale between 2002 and 2003; and for five scales between 2003 and 2004. Overall, between 2001 and 2004, the improvement in scale scores was statistically significant for seven learning environment scales, with effect sizes for these significant differences ranging from 0.21 to 0.38 standard deviations.

Over the 4 years of the study from 2001 and 2004, there was an improvement in students' perceptions of seven of the ten learning environment dimensions: Teacher Support with an effect size of 0.28; Involvement with an effect size of 0.36; Task Orientation with an effect size of 0.29; Investigation with an effect size of 0.38; Cooperation with an effect size of 0.20; Differentiation with an effect size of 0.25; and Young Adult Ethos with an effect size of 0.30. According to Jacob Cohen (1988), these effect sizes indicate 'moderate' changes between 2001 and 2004 and these seven dimensions.

The feedback information provided to the administrative staff at the end of the year proved useful for identifying professional development needs. Whereas comparisons between the different years of the school's operation were interesting in terms of getting a feel for whether the teaching efforts were going in the right direction, it should be noted that there were limitations in terms of the sample (i.e. there was a new cohort of Year 11 students arriving at the beginning of each year, as well as a cohort of Year 12 students).

The school involved in the present study adopted a whole-school approach in which all of the teachers embraced the use of a learning environment instrument and were supported by administrative staff. The TROFLEI provided a useful tool with which students' perceptions of their learning environment were monitored over the 4 years. The results provide some implications in terms of the pedagogy of outcomes education and curriculum change and implementation.

The approach followed in the present study helped teachers to examine and reflect on what they were doing in their teaching and to make changes that were more closely aligned with an outcomes-focused approach. It would be useful in the future to investigate whether the success of teachers was, in part, a result of a better understanding of the type of pedagogical activities involved in creating an environment that emphasises the dimensions assessed by the TROFLEI.

The results also provide implications for curriculum change and implementation theory. To successfully implement change, a clear understanding of the initiative is required by those responsible for managing the change (in this case, the teachers). In administering the learning environment survey and providing feedback, the teaching staff were given the opportunity to reflect on their own teaching and to 'tweak' their learning environments in ways that would enable a more outcomes-focused approach. The results suggest that the whole-school approach used at this school, in which all of the members of the school were involved in such change, was successful. It would be desirable in future studies, in which this whole-school approach is used, to determine whether monitoring the learning environment in this way is useful in other settings.

Overall, the field of learning environments provided useful techniques for monitoring the development of an outcomes-focused learning environment. The development of an instrument designed specifically to assess students' perceptions of an outcomes-focused learning environment proved useful to both the administrators and teachers involved in the study. The case study reported in this chapter illustrates the usefulness of this approach.

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Chapter 82
ICT Learning Environments and Science Education: Perception to Practice

David B. Zandvliet

Introduction and Conceptual Framework

The large-scale and increasing use of computers within society is a phenomenon that has continued apace for more than 30 years, and to some extent has been mirrored step for step within the educational system. The expanding use of information and communications technologies (ICTs) in schools is due in part to overwhelming technological and societal pressures, with this increasing focus on ICT being manifested not only in an increase in the numbers of computers in schools, but also in a diversification of their use.

In considering the new technological contexts that we find in our schools, many designers of educational spaces advocate for a closer integration of educational technologies, curriculum and instruction, and the design of suitable physical learning spaces. This suggests a greater role for teachers in all these varied processes. In this chapter, I consider holistically the importance of the learning environment in technology-rich settings using an ecological framework that was first developed by Gardiner (1989) and then later adapted for conceptualising school settings by David Zandvliet and Barry Fraser (2004a, b, 2005). The conceptual model consists of three overlapping spheres of influence that are described as, respectively, the *ecosphere*, *sociosphere* and *technosphere*.

In the model*, ecosphere* represents a person's physical environment and surroundings. Using this lens, researchers evaluate physical factors in computer settings in schools. For example, are certain types of pedagogy enabled or constrained by equipment or network configurations? *Sociosphere* relates to an individual's net interactions with all other people within that environment. Using this lens, researchers study the learning environment in classrooms. For example, are positive student

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perceptions created by using ICT? Which social factors are more closely associated with learning and other outcomes? Finally, *technosphere* describes the total of all person-made things in the world. Using this lens, researchers describe how ICTs are actually used in schools. For example, are strategies consistent with the goals and objectives of teachers, or are they impacted by other technical factors? Located at the intersection of these three spheres, the framework involves all people being subjected to these three influences.

ICT and Teaching Practice

While the numbers of computers and Internet connections in schools have steadily increased over the years, a survey by the National Center for Education Statistics (NCES 2002) revealed that 99% of full-time public school teachers in the USA reported having access to computers or the Internet somewhere in their schools, and 84% reported having at least one computer in their classrooms. Despite the reported increase in technological access only 20% of teachers were feeling well prepared to integrate technology into their teaching. These data seem to further imply that simply increasing the number of computers available for instructional use is not likely to lead to significant changes in instructional methods. Larry Cuban (2001) reports that teachers who use technology in instruction tend to use it to reinforce existing teaching practices. They claimed that, in addition to the availability of hardware and software, teachers' preparation to use technology in the classroom is a key factor in whether or not technology is actually incorporated into curriculum and instruction. Although the need for adequate training and support is well documented, professional development opportunities related to technology are often lacking according to Henry Becker and Jason Ravitz (2001) and NCES (2002).

According to a study conducted in California (California Educator 2003), the primary use by teachers when they have access to technology is email, especially to communicate between school and home. For students, the primary uses are word processing and Internet research. While these uses might be adequate for learning about technology, clearly ICTs are not being used to their full potential in enabling student learning. In a 2001 survey, public school teachers identified independent learning more frequently than professional development activities as preparing them for technology use (NCES 2002). In addition to a lack of training, the typical content of technology instruction for teachers is also reported as limited to computer literacy, with a focus on fundamental computer operation and standard applications rather than preparation on how to use technology as a pedagogical tool. Such thinking is further reflected in the standards that various districts have adopted regarding teaching, with teachers' need for a foundation in computer operations rather than pedagogical methods being clearly evident. Even the International Society for Technology in Education's (ISTE) educational technology standards for teachers include, as a first category of standards, basic computer/technology operations and concepts.

Kurt Sandholz and Anne Reilly feel that the expectation that teachers must be technical experts in fact might be working against greater technology use in classroom instruction. A common frustration for teachers who attempt to teach with technology is the amount of time spent on technical issues rather than instructional ones. In the early stages of implementing any new technology in laboratory settings, for example, teachers' concerns often centre on the technology itself and they are unable to focus on using technology in instruction until those technical needs are met. David Zandvliet (2006) claims that, with limited support, even teachers with well-developed plans for integrating ICT into classroom instruction often reduce or abandon them. This type of research data seem to point to the influence of technology itself (technosphere from the conceptual framework). More important in technology implementation is the teacher's pedagogical intent for using ICTs in the first place.

The Science Education Context

According to Lev Vygotsky (1978) and David Jonassen (1994), new technologies have indeed had an impact on science education and this has often been related to the use of ICTs as cognitive tools for students. These technologies have also led to changes in the goals for science courses to include outcomes such as technological literacy, while raising concerns about equitable access to technology. Marcia Linn (2003) highlighted a history of technology use in science education by exploring five key areas: science texts/lectures; science discussions and collaboration; data collection/representation; science visualisation; and science simulation/modelling. Citing a range of research, Linn claimed that these areas reflect two general trends of technological advance: first, designers have tailored tools to specific disciplines and, second, new tools allow for greater customisation for the user including user preferences and advances in our understanding of the learning process.

In the area of science communication and collaboration, for example, Ping Kee Tao (2004) studied the use of a computer-based collaborative learning instruction with Grade 10 students in Hong Kong. He found that students improved their understandings of the content, although this improvement ranged widely. Rich qualitative data about peer interactions in the study also suggested that students experienced conflicts and co-construction during these activities and that the learning environment was mediated by both the CAL software and the teacher during these social interactions.

In the area of computer visualisation and modelling, John Hansen and colleagues (2004) have described how certain strategies contribute to student learning about spatial scientific models, while other instructional strategies are more suitable for declarative types of knowledge in undergraduate science courses. Michael Piburn and colleagues (2005) have reported a study in which undergraduate geology students improved significantly on their scores for spatial visualisation after a study linking exposure to a series of multimedia instructional modules. While other content areas showed less improvement in the study, their findings also demonstrated a significant interaction between treatment and gender.

In another study, Noemi Waight and Fouad Abd-El-Khalick (2007) investigated the impact of computer technology on the enactment of inquiry in a sixth grade classroom. Using a range of methods, researchers followed the class through 4 months of ‘inquiry’ activities. They found that ICT used in the classroom often worked to restrict rather than to promote inquiry. They further reported that, in the presence of computers, group activities became more structured with a focus on sharing tasks and individual accountability and less time being spent on meaning-making and collaborative group discourse. They advised that the views and perceptions of teachers and students in relation to specific learning environments could moderate the effectiveness of any technology in meeting stated or expected learning outcomes.

Morgan Webb (2005) concluded that there is a range of affordances for the use of ICT in science education. She reported that a range of innovations can be supported by the use of ICT and identified four main effects for the use of ICT specifically in teaching science: promoting cognitive acceleration; enabling a wider range of experience; increasing students’ self-management; and facilitating data collection and presentation. Webb concluded that, in order to plan and select appropriate practices, teachers need to understand the relationship between the affordances of ICT resources and their own knowledge of concepts, processes and skills in a subject area. All of this implies a more detailed understanding of learning environments when using ICTs.

Learning Environments: The Social Context for ICT Use

Clearly, infrastructure, professional development and new curricula are important components in implementing ICTs into schools. However, it is also important to broaden our discussion to include the social context (sociosphere) of students in order to evaluate a range of outcomes from this investment in a new (and some say unproven) educational resource. A promising methodology which has been used to investigate both the effects and affects of the integration of ICT into school classrooms is found in an area of the academic literature described as the study of ‘learning environments’ (Fraser 1998).

A foundation for the study of school learning environments was developed in the independent work of Herbert Walberg (1979) and Rudolf Moos (Moos and Trickett 1987). Over the ensuing decades, many studies have built on this work and applied it to educational settings as described in detail elsewhere by Barry Fraser (1991, 1994, 1998). Many of these instruments include scales that have proven to be effective predictors of student achievement, behaviours and attitudes. This chapter now extends a discussion of learning environment research to a focus on learning environments where information technologies are used.

ICT-Rich Learning Environments

Studies reviewed by Fraser (1998) and describing psycho-social learning environments have demonstrated much about the factors that could influence or determine learning in classrooms. Other educators are adding their findings to the body of research within the fields of psychology, sociology, physiology, architecture and engineering. In part, the interdisciplinary nature of learning environments research points to the diversity of factors involved, including student perceptions of constructs such as independence, cohesion and motivation, but also encompassing perceptions of a variety of physical or material factors as well (Zandvliet and Fraser 2005).

Myint Swe Khine and Darrell Fisher (2003), in their important compilation of studies on technology-rich learning environments, stated that the proliferation of ICT tools in recent years has led many educators to revise the way in which they teach and structure their classroom learning environments. This book provides a range of research and case studies that explore how technology-rich learning environments can be structured and how more positive educational outcomes can be achieved. A number of promising forms of research described in this volume included: the validation of new learning environment instruments for online learning; studies of the effectiveness of technology-rich and outcomes-focused learning environments; and a range of case studies of strategies or pedagogical styles for implementing ICTs in various educational settings. Since this earlier work, studies of the learning environment in technology-rich settings have continued to include a range of contexts. What follows is a selection of some recent research findings which demonstrate the growing scope of this research.

Garry Falloon (2006) has documented key findings from an 18-month case study into a learning environment (involving Grade 5 and Grade 6 students) at a suburban primary school in New Zealand. He examined the nature of teacher and student work practices in an environment where every two students shared a computer for their lessons. The findings portrayed a complex interrelationship between teacher philosophy, curriculum design and classroom organisational systems, which are factors which significantly impacted on student work and social performance. The study also presented and discussed video footage which enabled unique 'insider views' into the ways in which students worked with the teacher, each other and the software as they worked in their ICT-rich learning environment.

Jeffrey Dorman et al. (2006) presented findings from the use of structural equation modelling in investigating associations between classroom environment and outcomes in Australian secondary schools. Their 80-item Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) was used to assess ten different classroom environment dimensions. A sample of 2,178 high school students responded to the TROFLEI and three student outcome measures: attitude to the subject; attitude to computer use; and academic efficacy. Confirmatory factor analysis (using LISREL) supported the ten-scale a priori structure for the instrument. Multiple regressions identified particular classroom environment scales that were significant independent predictors of the outcomes. For example, the scales of teacher support and equity predicted attitude to subject and the scales of differentiation, task orientation, computer usage and student ethos predicted attitude to computer use. Their findings indicated that improving classroom learning environments has potential to improve a range of student outcomes.

Kerry Logan and colleagues (2006) reported an effort at redeveloping the College and University Classroom Learning Environment Inventory (CUCEI) that was originally developed in 1987. They reported that the CUCEI was modified and used during two independent studies in computing classrooms in secondary classrooms and tertiary institutions in New Zealand. The authors reported some ways in which to enhance the validity and reliability of such instruments for use in ICT-rich environments – in part a testament to the complexity of learning environments research in this type of setting. In this study, the authors reported that the performance of the instrument was not completely satisfactory.

Scott Walker and Barry Fraser (2005) developed and validated a learning environment instrument for use in psycho-social learning environments in post-secondary distance education. The Distance Education Learning Environment Survey (DELES) was developed and field-tested with 680 distance education students and then validated. The instrument assesses instructor support, student interaction and collaboration, personal relevance, authentic learning, active learning and student autonomy. An additional scale of enjoyment was included in the study to permit exploration of associations between the learning environment and student affective traits. The resulting instrument treats distance learning as having a social-psychological climate that is distinct from those found in other types of post-secondary classrooms.

Finally, Adam Handelzalts and colleagues (2007) reported a study of the development of an instrument to measure Dutch pre-service teachers' perceptions of ICT-infused learning environments (in this case the Study Landscape) that encourages pre-service teachers to direct their own learning in order to build a two-way relationship between theory and teaching practice. This study involved both qualitative and quantitative methods in identifying six factors to form the basis of the new instrument: support of learners' initiatives; support of information searches; support of interaction; relationship with fellow students; relationship with teacher-educators; and relationship with technical staff.

In addition to the above studies, I have collaborated on numerous interrelated studies of the learning environment in high-school-based ICT settings in Australia and Canada with Barry Fraser (Zandvliet and Fraser 2005), in Canada with Laura Buker (Zandvliet and Buker 2003), in Malaysia with Umar bin Man (Zandvliet and bin Man 2003) and in Taiwan with Chia-Ju Liu (Liu and Zandvliet 2009). These studies are important as they share the conceptual framework described at the beginning of this chapter and because they used the same research instruments applied in different educational and cultural settings. Excerpted data from these case studies are presented in the next section to further describe how learning environment studies in ICT-rich settings can be conceptualised and applied.

Perceptions of ICT-Rich Environments in Four Countries

Overview of Study Methodology

The environment identified for study in each of the four countries reported here can be described as 'technologically rich'. This type of setting was identified as having a number of networked computers, with the general availability of Internet resources for students and their substantial use in the delivery of curriculum. The range of settings included laboratories, and a variety of classroom-based implementations. ICT was presented in various configurations with varying numbers of computers at each location. All of the schools in the four study contexts were high schools and, in the case of the Malaysian sample, formed a part of a systemic educational reform effort. In each study context, the rationale for the technology was consistent with pedagogical implementations of technology in that the intent of the ICT was to support constructivist, reform-minded ideas about teaching and learning.

For each study classroom, a general profile of the learning environment was constructed by evaluating a number of selected psycho-social and physical (contextual) factors, and then validating the results by intensely (qualitatively) investigating a subset of the original sample. A number of different methodologies were used to accomplish this: first, questionnaires and inventories were administered in a wide range of settings; and, second, semi-structured interviews were conducted with selected teachers and students working in these locations. Student satisfaction was seen as a major dependent variable for the studies as it has been previously shown to be a predictor of learning in school settings and of productivity in education and workplace settings.

The measures for all case studies were obtained by administering five scales selected and adapted from the original version of the What Is Happening In this Class? (WIHIC) instrument, originally developed by Barry Fraser et al. (1996). The WIHIC has been shown to have high reliability and validity in a variety of settings. Further, the instrument had been validated in a number of different languages and contexts. Scales measuring cohesiveness, involvement, autonomy, task orientation and cooperation were selected for the studies as they were viewed as consistent with the goals of reform efforts aimed at individualising curriculum and instruction and increasing student interactions. The WIHIC was administered in each context to students and they were asked to reflect on their perceptions of the *actual* ICT environment as they experienced it. The unit of analysis was the individual classroom or laboratory. As an additional (conceptually different) measure, surveys also included items assessing students' satisfaction with learning (Fraser 1981).

Administration of Surveys

As noted, the WIHIC questionnaire was selected for describing the social context for ICT use as it had proved a reliable and valid instrument in earlier studies.

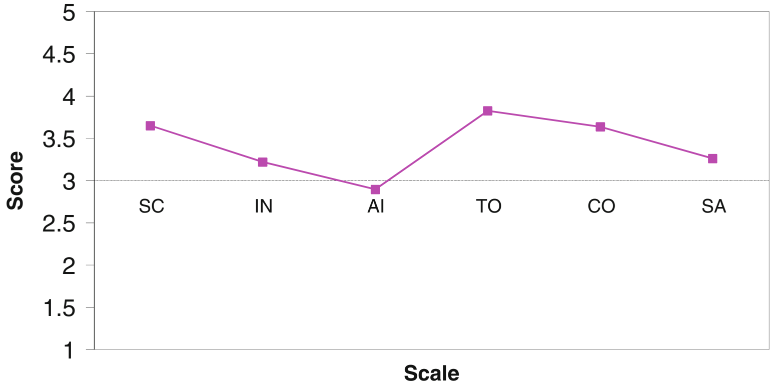

Fig. 82.1 Mean scores (WIHIC and TOSRA scales)

For each study reported here, questionnaires were distributed in class sets to teachers who were working in ICT-rich settings. Mean scores for each class were calculated for each study using individual scale scores and aggregating the data by class. Reliability and validity data for each administration of this questionnaire are reported elsewhere (Liu and Zandvliet 2009; Zandvliet and bin Man 2003; Zandvliet and Buker 2003; Zandvliet and Fraser 2004a, b, 2005). Analyses revealed that scales were valid and reliable in the four different study contexts (including translated/back-translated versions used in Malaysia and Taiwan) and further corroborated qualitative findings linking psycho-social factors with students' satisfaction with learning.

Interpretation of the student questionnaire data yielded an important perspective on the learning environment in ICT-rich settings. Although there was variability in ratings, overall, students perceived most aspects of their learning environments to be positive and characterised them as being higher in student cohesiveness, cooperation and task orientation than other scales such as involvement. Importantly, the scale of autonomy/independence had the lowest scores of the five learning environment scales, indicating a slightly negative perception of this factor. However, students did rate their level of satisfaction with learning in these environments as generally positive.

The survey data presented as an example of the study results in Fig. 82.1 have been aggregated from the Malaysian context (Zandvliet and bin Man 2003) and can be taken to be representative of the trends in all studies. These data describe ICT-rich settings as 'semi-autonomous' as this aspect of the learning environment was rated lowest in all of the international contexts studied. For example, in a 2004 study by David Zandvliet and Barry Fraser, the use of the WIHIC revealed that student perceptions of autonomy/independence was rated as negative relative to other learning environment measures in ICT-rich settings in Australia and Canada. This trend was consistent with findings from David Zandvliet and Laura Buker's (2003) study in which student perceptions of autonomy/independence were once again rated negatively by Canadian students.

Semi-autonomous Learning Environments

In the absence of empirical data to support the lower ratings of autonomy and independence reported by students in these studies, the phenomenon also could be related to teachers' perceived competence with ICT in these settings and the dominant form of technology use (Zandvliet 2006). The results might indicate an international trend in which student perceptions regarding autonomy might be negatively influenced by the dominant form of technology implementation (computer laboratories). While other aspects of these ICT-rich learning environments seem to be rated by students positively, the negative ratings on the scale of autonomy and independence are particularly problematic as educators see this as a goal for the implementation of ICTs.

Clearly, one of the affordances of computer technologies in past educational discourse has been their perceived ability to deliver individualised instruction. In fact, many hardware and software designers assume that all technology-assisted instruction should be structured individualistically. Chet Bowers' (2001) critique is that computers are envisioned to empower individuals by making available massive amounts of data resulting in an 'amplification of the autonomous individual'. However, the idea of computers amplifying student autonomy might refer only to an illusion of autonomy. To make this point in a different way, Bowers (in a personal communication) stated that the computer could hide the reality that language and words have a history, and that their current meaning or analogue is represented as objective rather than as having different meanings in different cultures.

The idea that ICT-rich environments and student ratings of autonomy might be culturally mediated seems to be substantiated by recent (and ongoing work) in the Taiwanese context by Chia-Ju Liu and David Zandvliet (2009). In a recent study which also confirmed the trend of low student ratings of autonomy in ICT-rich settings, Taiwanese students differentiated among three different constructs of autonomy provisionally described as *autonomy of expression*, *autonomy of decision* and *autonomy of choice*. While further qualitative work is needed to explore the implications, the findings suggest that students' perceptions of autonomy in these settings are more complex than previously considered. Many scholars such as Chet Bowers (2001) suggest learning (in all its forms) would be better served by improving the connectivity in the learning environment by actions on cultures rather than on individuals. Implied in this view is the idea that educational practice is essentially a socio-cultural activity and not individualistic as implied by software design or the inception of computer laboratories to deliver instruction.

Physical Considerations in the Implementation of ICT

A final lens through which ICT can be viewed is through the influence of the ecosphere (the built environment of schools). Analysis of qualitative data from learning environment case studies reported here also indicated that negative perceptions regarding aspects of the learning environment were often due to architectural or technical implementation factors in ICT related to the use of computer laboratories rather than classroom implementations. As noted, by David Zandvliet and Leon Straker (2001), students' low ratings of autonomy also could be due to a number of factors, including deficiencies in physical or ergonomic factors in laboratories or other types of settings.

The design of a typical school computer laboratory illuminates just some of the ecological relationships in a poor design for an educational setting described by Catherine Loughlin and Joseph Suina (1982) and Khe Kroemer and Etienne Grandjean (1997). The failure to consider pedagogical flexibility in the design of computer laboratories contributes to the possibility that these laboratories can become a de-socialising influence on students. To some extent, the design of many laboratories replicates the earlier technocentric and bureaucratic design considerations (witnessed by rigidly designed rows of computers). In replicating the basic design of computer laboratory settings from business and industrial settings, David Zandvliet and Leon Straker consider that we have essentially neglected to consider the educational implications of these settings on the educational process and, in so doing, we have constrained teachers and students from the related tasks of teaching and learning (Zandvliet 2006; Zandvliet and Straker 2001).

As a final example, the study by David Zandvliet and Barry Fraser (2005) further illustrates the point that computer laboratory implementations can influence the learning environment of students. The association between the number of workstations in a setting and the learning environment was considered. To investigate this issue, multiple and linear regression analysis was performed using number of workstations as a dependent variable regressed against five psycho-social variables and the satisfaction scale derived from the questionnaire data in an Australian study. The learning environment scale of involvement was negatively associated with the number of computers. While other comparisons were made, no positive associations were demonstrated between the number of computers and the learning environment or the variable satisfaction. A (negative) correlation with autonomy was also noted.

The negative association noted between the number of computers and the involvement scale is important. This relationship would seem to suggest that increasing the number of computers in a setting is potentially counterproductive as students become less involved with their ICT-focused lessons. This idea gains greater importance when it is considered that no positive associations with the number of computers were identified in this research, or in any of the related studies in other countries. These data suggest that this type of implementation of ICT, if not managed carefully, can have negative consequences for learning environments generally and for supporting diverse practices in science teaching and learning.

Conclusion

This chapter has documented a decade of international research on learning environments in science classrooms using information and communications technologies. Organised around a conceptual framework that involves an ecological view of ICT that considers relevant technical, social and physical factors related to the use of ICTs, the chapter then described evaluations of both physical and psychosocial classroom environments in ICT settings in four different international contexts. These case studies suggest how different cultural interpretations of technology could influence the learning environment in various educational settings. The research findings also suggest the need for a closer integration of educational technologies, curriculum and instruction, and the design of suitable physical learning spaces for science education. Further research exploring the relationships among learning environment constructs and other outcomes, such as student attitudes, motivation or achievement, are required to build on the existing body of research on science learning environments in technology-rich settings.

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Chapter 83
Cultivating Constructivist Classrooms Through Evaluation of an Integrated Science Learning Environment

Rebekah K. Nix

The strategic incorporation of information technology (IT) into teacher education can foster constructivist teaching and learning practices in school classrooms. One design, the Integrated Science Learning Environment (ISLE) model, uses IT to holistically combine a variety of approaches to develop constructivist milieus. The goal of ISLE, common to other approaches as well, is to improve science education by bringing about conceptual change through authentic inquiry. According to Rosalind Driver and colleagues (1994, p. 7), "The challenge lies in helping learners to appropriate these models for themselves, to appreciate their domains of applicability and, within such domains, to be able to use them." Drawing on first-hand experience as a science teacher educator, this brief examination expands current themes described in the context of two different ISLE programs.

With the array of valid and reliable tools and efficient and simple techniques reviewed by Barry Fraser (2007), learning environments research adds an important perspective on documenting if and how programs are having an impact on school science. A common use of classroom environment assessments has been as dependent variables in evaluating educational innovations, as illustrated by Catherine Martin-Dunlop and Barry Fraser (2008). Integral to the ISLE model, innovative research methods used new forms of the Constructivist Learning Environment Survey (CLES) to quantify teacher and student perceptions of the emergent learning environments as dependent variables. Changing the teachers' learning environment was found to be associated with a similar change in their respective school learning environments, which can be linked to improved attitudes toward and achievement in science.

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The purpose of this chapter is to encourage further innovations for improving practice and research in science education. After briefly describing the current context for reform, the following sections provide a closer look at technology-rich learning environments, the basic framework of the ISLE model, how the CLES enables multilevel evaluation of ISLE programs, and how some teachers are realizing positive change in today's science classrooms.

Re-forming New Learning Environments

Recent and rapid advances in science and technology have initiated a ripple that is reshaping the traditions of science education through distance education and teacher education. Regarding science teacher education, Robert Sherwood and Deborah Hanson (2008) reported that, despite limited NSF funding during 1996–2006, "several projects have been able to show results that have made their way into the peer reviewed literature" (p. 31). Increased interest in both teaching and learning combined with the political and social attention to education on a global scale has supported similarly rapid and significant advances in learning environments research (Fraser 2002). For example, Younghee Woo and Thomas Reeves (2007) elaborated how technology can enable more meaningful interaction – "an essential ingredient in any learning process" (p. 15) – in web-based learning. "Adopting new educational practices that promote the development of critical thinking, collaborative skills and creative ability constitutes a social demand of our time" (Pedagogical Institute 2002, p. 6).

Classroom teachers demonstrate wide individual differences in content knowledge and pedagogical skills that impact on the learning environment that they create for their students. On reviewing studies of curriculum integration for over a decade, John Wallace et al. (2007) noted that "the energy and goodwill of the participants in the reform process, and their capacity to translate reforms into positive classroom experiences, make the difference in changing classrooms" (p. 30). By placing science-related content into perspective and applying the principles of collaborative problem solving in a real-world setting, the ISLE model supports and encourages teachers in the implementation of new technologies and teaching strategies through activities that promote personal growth. With successful transfer, the same techniques used to deal with issues in the university are applied to integrating new understanding and expertise in schools.

In terms of evaluating ISLE programs, of primary theoretical importance, the scales of the CLES directly support the goals of educational reform. Table 83.1 matches the CLES scales to the standard stated as the primary goals for educational reform in the USA.

It is of primary methodological importance that numerous past studies available in the scholarly literature confirm the validity of the CLES in numerous countries and its usefulness in various research applications. Results reported in 15 studies since 1995 with direct relevance to ISLE evaluation validated the CLES with 11,632 students ranging from kindergarten to adult. English, Korean, Mandarin, and

Table 83.1 CLES scales matched to learning environment goals for educational reform in science

CLES scale	Science learning environment standard statement
Personal Relevance	"Teachers help students learn about and internalize the values inherent in the practice of science by relying on those values to shape the ethos of the learning community."
Uncertainty of Science	"…they (the teachers) work diligently to establish a congenial and supportive learning environment where students feel safe to risk full participation, where unconventional theories are welcomed, and where students know that their conjectures and half-formed ideas will not be subject to ridicule."
Critical Voice	"…teachers recognize that the emotional response of some students to a lively, argumentative, inquiry-based classroom might never to venture an opinion or idea, thereby avoiding the risk of public failure."
Shared Control	"Accomplished science teachers deliberately foster settings in which students play active roles as science investigators in a mutually supportive learning community."
Student Negotiation	"They (the teachers) foster a sense of community by encouraging student interactions that show concern for others, by dealing constructively with socially inappropriate behaviour, and by appreciating and using humour."

(National Board for Professional Teaching Standards 2001, p. 25)

Spanish versions were administered in Australia, Korea, South Africa, Taiwan, and the USA (Florida, Iowa, Minnesota, Ohio, and Texas). For example, Sharon Harwell and colleagues (2001) used the CLES in university–school collaborative action research while integrating technology into the curriculum. Although there were no significant changes in student perceptions of the classroom learning environment, results led teachers to construct a new set of questions and a new plan of action to bring their classroom learning environments into closer alignment with a constructivist perspective for teaching and learning. Significant cross-validations of translated versions of the CLES have been reported among Korean students by Heui-Baik Kim et al. (1999) and among Taiwanese students by Jill Aldridge et al. (2000).

Technology-Enriched Learning Environments

In the ISLE model, real-world applications of relevant tools and resources are covertly employed to join the university classroom and field experience seamlessly. The focus is intentionally shifted from the details of hardware and software to finding ways to improve teaching and enhance learning through the most appropriate method(s). The first ISLE evaluation of a teacher outreach program was conducted in 2000, before the university had a reliable online course management system and before the department had practical mobile technologies for teaching and learning science. Throughout this one-semester intensive course, a virtual field trip was used to improve teaching efficiency and effectiveness by providing a dynamic and accessible interface to specific information for review and reference. The teachers were active contributors from the start as assignments required them to conduct searches for appropriate websites related to their personal and professional interests, access files and forms from the archives, and help to build and use the water chemistry database in real time. As a group, participants created a top-level concept map to represent the goal of their field studies that reflected the main topics: ecology, geology, information technology (implicit in the supporting materials), humankind, and the environment. This provided a prescribed framework in which to collaborate, along with a purpose and direction for focusing their individual reports. During the 2004–2005 academic year, a second ISLE study involved evaluating a three-semester teacher quality program. Five topical units were linked through culminating "teaching roadmap" presentations. Matched participants teamed to weave complementary experiences into multidisciplinary projects that defined the lesson context, pedagogical framework, logistical framework, classroom application details, and cross-disciplinary connections. This helped to transform the facts gathered from an independent, subject-based division into an integrated, concept-based continuation. Teacher understanding developed as the focus flowed from general observations to specific details and back to the increasingly sharper "big" picture.

Regardless of the context and content, implementation of IT strategically reinforces the conceptual design and therefore is evident in all stages of an ISLE program. During pre-trip segments, appropriate use of IT is demonstrated through: modeling, as teachers experience the integration of technology; observing, as teachers see technology applied for everyday operations; and researching, as teachers search the Internet for references and resources. In the field locale, appropriate use of IT is evident in: training, as teachers demonstrate the functionality of a range of tools; sampling, as teachers collect real-time data using various devices; and analyzing and interpreting information, as teachers record and manipulate data with technology-enabled resources. During post-trip follow-up, appropriate use of IT is demonstrated through: facilitating, as instructors help teachers to support the presentation of content with applications of technology; organizing, as teachers outline their reports and verify their content with electronic sources; and producing, as teachers use software tools to create their contributions to the final product.

Bringing teachers, technology, students, and learning together requires a new model of education that is practical for today's teachers and suitable for tomorrow's students. According to Clayton Christensen and colleagues (2008, p. 91) this notion is supported by the fact that "public education enrollments in online classes… are exhibiting the classic signs of disruption as they have skyrocketed from 45,000 in 2000 to roughly 1 million today." Simply "cramming" technology into traditional instructional practices does not automatically increase student-centered learning and project-based teaching. Demonstrating what is possible, Ann Novak and Joseph Krajcik (2006) detailed ways that learning technologies have been embedded into practice to support children in acquiring deep and integrated understandings. Fortunately, the same technologies that have enabled "anywhere-anytime," science in the real-world have equipped more people to learn "everywhere-all-the-time," thus creating new realms for leveraging learning environments research. However, for now, challenged by stretched budgets (time and money), most science education and teacher education still occur within established classroom limits.

The Integrated Science Learning Environment (ISLE)

"In an era of dramatic new technology resources and new standards in science education in which learning by inquiry has been given renewed central status," Avi Hofstein and Vincent Lunetta (2004, p. 28) updated their 1982 review of research on the school science laboratory. Among other things, they added two studies in which student perceptions of science laboratory learning environments suggested open-endedness (the extent to which the activity emphasizes an open-ended approach to investigation) and integration (the extent to which the laboratory activities are integrated with non-laboratory activities in the classroom) were important outcomes. Many other successful studies have aimed to integrate certain technologies or assessments or disciplines or activities. For example, Carol Stuessy and Jane Metty (2007) documented the impact of a science teacher's participation in the Learning Research Cycle, a model designed to bridge research and practice in both university and public school contexts. To emphasize connections between the eight stages, a web-based "community portal was used to connect teachers, graduate-student mentors, instructors, and scientists in and across small mentoring groups and summer classes" (p. 729).

Three key aspects distinguish the ISLE model from other teacher development programs:

1. ISLE models the integration of IT into the university classroom and curriculum, as they might be implemented in the school classroom. By actually experiencing the appropriate and effective use of IT in educational practice, teachers can appreciate the value of new tools and resources.
2. ISLE encompasses the field trip, as well as the university and school classroom milieus. By focusing on the common element, the individual, experience can be internalized and thereby naturally transferred among the physical settings.
3. ISLE seamlessly presents IT as a means to an end, not the end itself. By selecting and applying appropriate tools and resources, the benefits (rather than the challenges) can be maximized.

Figure 83.1 shows how a divergent affective approach can be shifted to realize a single effective plane defined by each unique learner. The instructor strategically teaches along distinct axes while students independently adjust their positions along each until the conceptual frameworks merge for meaningful learning that naturally transfers into other settings. This realization occurs throughout a program due to variations in prior knowledge and learning preferences.

A novel sequence of experience, reflection, generalization, and application centered on a single CLES scale provides the scaffolding for each class, as well as for

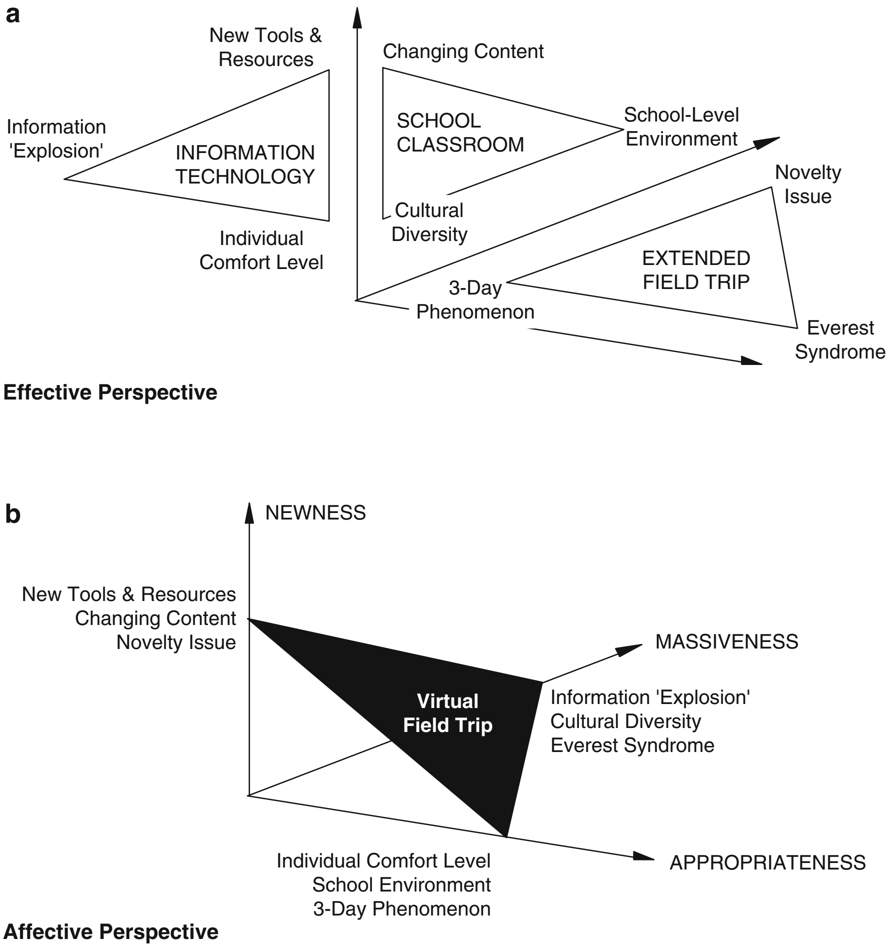

Fig. 83.1 Merging of perspectives through the ISLE model

each lesson within the class. The cyclical repetition illuminates the commonalities and interdependencies of each concept. Participants are exposed to activities and instruction in a repeated hierarchical fashion. Movement along any one of the three major axes can catalyze change along each of the two other axes in the ISLE model. Regardless of the form, the key to attaining true integration is to create a comfortable framework to guide exploration and enable discovery that incorporates an interactive sequence of experience and reflection for teachers and their students. Innovative models for science education are being designed with the intention of, as explained by James Zull (2002), "creating conditions that lead to change in a learner's brain. We can't get inside and rewire a brain, but we can arrange things so that it gets rewired. If we are skilled, we can set up conditions that favor this rewiring, and we can create an environment that nurtures it" (p. 5).

Constructivist Learning Environment Survey (CLES)

In the Project 2061 *Blueprints for Reform* (AAAS 1998), one suggested approach for improving science teacher education is that "students should be allowed to become active learners, have first-hand experience with making connections between their own ideas and the knowledge they develop in courses, and participate in classes where faculty model a teaching style that is conducive to active learning" (Teacher Education, ¶ 11). The generally accepted principles of constructivist teaching guide the design of ISLE-based programs, providing a common thread throughout the coursework and the formative and summative evaluation of the program. In response to the need to assess innovative classroom environments, like ISLE, the CLES was developed by Peter Taylor et al. (1997) with a psychological view of learning that focused on students as co-constructors of their own knowledge. A unique aspect of the CLES is that items from the same scale are grouped together. The original 30-item version contains six items with a five-point frequency response scale (5 = Almost Always, 4 = Often, 3 = Sometimes, 2 = Seldom, and 1 = Almost Never) in five scales:

1. Personal Relevance (relevance of learning to students' lives)
2. Uncertainty of Science (provisional status of scientific knowledge)
3. Critical Voice (legitimacy of expressing a critical opinion)
4. Shared Control (participation in planning, conducting and assessing of learning)
5. Student Negotiation (involvement with other students in assessing viability of new ideas).

The impact of the ISLE program on teachers and their students was investigated through multiple administrations of the CLES, including two modified versions described by Rebekah Nix et al. (2005). Figure 83.2 shows how different participants are able to evaluate two different learning environments using three versions of a single instrument. At the end of formal instruction, the adult form is used to assess teacher perceptions of the university teaching. Several months later, the comparative teacher form allows the same teachers to assess the degree of constructivist practice in the learning environments that they create as teachers in their school settings. This evaluation is supported by their respective students' assessment of the degree of constructivist practice in the same school classroom on the comparative student form. With two separate response blocks for each item presented in side-by-side columns (THIS and OTHER), the CLES-CS asks students to compare the degree to which they felt that the principles of constructivism have been implemented in the class taught by their ISLE teacher (THIS) relative to classes taught by other teachers in their school (OTHER).

Using data collected from 1,079 students in 59 classes in north Texas, principal components factor analysis with varimax rotation and Kaiser normalization confirmed the *a priori* structure of the 30-item CLES-CS. The factor structure, internal consistency reliability, discriminant validity and the ability to distinguish

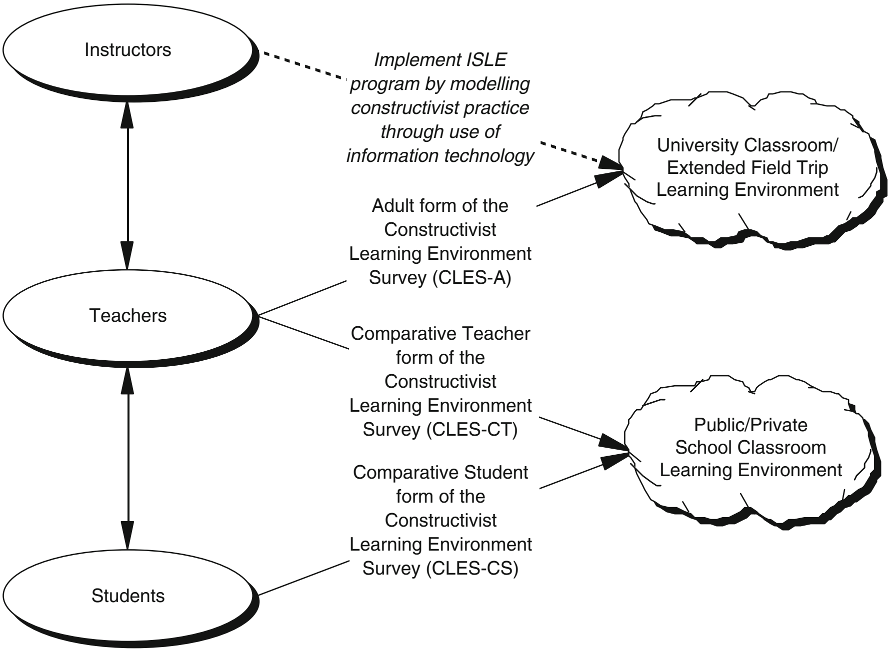

Fig. 83.2 Multilevel assessment of ISLE model enabled by three versions of the CLES

between different classes and groups were supported for the comparative cases of the CLES-CS (Nix et al. 2005). Concurrent with the first ISLE study (Nix 2002), Bruce Johnson and Robert McClure (2004) developed a shorter and modified CLES and, for a different sample of teachers and students, reported that the new version exhibited strong internal consistency reliability. Consequently, it was used for the second ISLE evaluation. The uncertainty scale was omitted (because of its limited direct relevance to the overall study) to form a 16-item four-scale version (CLES2). For the responses from a second ISLE sample of 845 school students, principal axis factoring with oblique rotation and Kaiser normalization was conducted separately for the 16 items of the CLES2-CS for THIS and OTHER cases. The *a priori* four-factor structure was replicated perfectly and every item was retained (as its factor loading was greater than 0.40 on its own scale and less than 0.40 on the other three scales). The proportion of variance accounted for by different scales ranged from 6.77% to 16.19% (with a total of 44.17%) for THIS class and from 6.44% to 15.15% (with a total of 42.27%) for OTHER classes. Overall, results support the factorial validity of the 16-item CLES2. The alpha coefficients of different scales ranged from 0.60 to 0.97 for THIS and from 0.62 to 0.77 for OTHER, representing satisfactory reliability for these shorter scales.

Changing Science Classroom Learning Environments

Learning environments research has a broad range of applicability for today's diverse educational issues. These ISLE studies provide another example of the use of learning environment variables in educational program evaluation. A combination of qualitative methods and quantitative measures (Tobin and Fraser 1998) provided insight into the near- and far-term effects of the ISLE programs to answer the general question of whether changing teachers' learning environments might affect a change in their respective students' learning environments. Modified and shortened versions of the CLES were found to be valid, economical, and useful for program evaluation. Limited to the north Texas area, quantitative data suggest that, in terms of the scales of the CLES, instructors were successful in fostering a constructivist learning environment in the university classroom as perceived by the teachers, and participating teachers were successful in fostering more constructivist learning environments compared to other classrooms at their same school as perceived by their school students.

By creating a virtual field trip product in the first ISLE implementation, both science and nonscience teachers interconnected the ISLE experiences to support their specific teaching areas. Using the individual student as the unit of analysis, differences between the classroom environments of the ISLE science teachers and of other teachers in the same school were statistically significant ($p < 0.01$) for Personal Relevance and Uncertainty of Science. Also, for Personal Relevance and Uncertainty of Science, differences between the science classroom learning environments of ISLE teachers and of teachers who attended alternative field trip programs not based on the ISLE model were statistically significant ($p < 0.01$). In light of qualitative evidence, effect sizes suggested that the ISLE program could be educationally important for improving the learning environment indicators over which the teachers evidently feel that they have some control. Although the first evaluation of the ISLE model within a summer short course attested to the model's success, it is noteworthy that the effect sizes were considerably larger in the second evaluation of the model over a three-semester time period. Using the CLES2-CS, the effectiveness of the second and longer ISLE program was evaluated partially in terms of the degree to which teachers implemented constructivist pedagogy in their secondary school classrooms, as perceived by the 845 students of the science teachers who had experienced ISLE. Differences between the classroom environments of the classroom environments of the ISLE science teachers and of other teachers in the same school were statistically significant for all four CLES scales (Personal Relevance, Shared Control, Critical Voice, and Student Negotiation), indicating that students perceived the participant teachers' classrooms as more constructivist than other teachers' classrooms in the same school. As suggested, the smaller effect sizes (around one-tenth of a standard deviation for Student Negotiation) could suggest areas over which the school administration appears to have strict control. By the same token, the larger effect sizes (nearly one standard deviation for Personal Relevance) suggests that the program could have had an educationally important

Table 83.2 Constructivist Learning Environment Survey scales matched to pedagogical aspects of information and communication technology use in science education

CLES scale	Implications of ICT affordances for teachers and students in an integrated pedagogy
Personal Relevance	"Teachers need to know about these affordances and… then need to use this knowledge of affordances together with a wide range of other types of knowledge… to plan activities that will lead to learning and will motivate their students."
Uncertainty of Science	"Computer simulations, Internet-supported student research projects and computer-based modelling provide new affordances that enable students to gain a wider range of experience relating to science in the real world."
Critical Voice	"The affordances provided by ICT-rich environments to support students' self-management free teachers to focus on questioning and negotiation of meaning."
Shared Control	"… the development of formative assessment pedagogy has enabled students themselves to identify their needs, and hence play a larger role in planning for their learning."
Student Negotiation	"Increasing discussion between teachers and students about learning processes and opportunities for learning will enable students to negotiate the planning of their own learning."

(Webb 2005, pp. 728–729)

effect in improving the indicators over which teachers evidently feel they have some control. Overall, the data suggest that the emergent programs were effective in terms of the degree of implementation of constructivist teaching approaches in the ISLE teachers' school classrooms, as perceived by their students.

Consistent with previous studies, the ISLE model offers a broad context for enculturation of the constructivist paradigm. Because of the influence of numerous school-level factors, this sort of pedagogical change is difficult to realize in individual classrooms according to Catherine Milne and Peter Taylor (2000). In the second ISLE study, qualitative data led to four main assertions with respect to the implementation of constructivist teaching–learning practices:

- An interdisciplinary team approach to program design and delivery provides a critical perspective.
- Teacher efficacy must be founded on a solid base of content knowledge.
- A teacher's intimate and practical understanding of a subject is prerequisite for successful incorporation of new pedagogical skills.
- A working knowledge of and the availability of new tools and current resources, along with an active peer network, ultimately determine a teacher's facility to enhance his/her students' learning environment.

In terms of the implications of the potential for technology-rich science learning environments, the scales of the CLES can also be linked to pedagogical practices. Table 83.2 matches the CLES scales to excerpts from a proposed framework developed from a focused review of information and communication technology (ICT) use in science education (Webb 2005).

A growing body of literature indicates that the ability to investigate learning environments in longitudinal, cross-cultural, and multidimensional studies conducted across grade levels, content areas, and contexts enables versatile designs that can illuminate critical associations of theory and practice that can be overlooked or underestimated in one-time, localized or field-delimited research. By jointly considering the physical and psychosocial learning environments in a single study of Canadian and Australian students' satisfaction, David Zandvliet and Barry Fraser (2005) identified important factors for a new model of educational productivity in computer-networked classrooms. Similarly, learning environments research offers great potential for improving science teaching and learning as collaborators seek to bridge the gaps between traditionally separated fields. For instance, despite scientific and pragmatic challenges for bridging education and neuroscience (Varma et al. 2008), one evaluation significantly established a causal relationship between the improvement of Grade 9 earth science students' learning and the utilization of Visual Thinking Networks (Longo et al. 2002). Already underway, preliminary results from testing for the third implementation of the ISLE model indicate that the same metacognitive learning strategy improved abstract reasoning abilities in adult learners enrolled in an integrated distance education course for science teachers (Nix and Longo 2008). Designed to exploit multiple technologies and alternative assessments, the modular content is one more step toward a truly student-centric model for science teacher education. Supported by the American Educational Research Association's release of *Estimating Causal Effects Using Experimental and Observational Design* (Schneider et al. 2007), the next step is to explore ways to connect learning environment correlations to neurocognitive causes to inform future action research that science teachers can conduct within their ever-changing classrooms. As suggested by John Cannon (1997), "the CLES could be used as a means for the teachers [of college courses] to measure the efficacy of their efforts to move to more constructivist-oriented teaching and learning environments" (p. 70).

Barry Fraser and Jane Kahle's (2007) secondary analysis of 1995–1997 data from Statewide Systemic Initiatives found that "the classroom environment (defined as the use of standards-based teaching practices) accounted for variance in both achievement and attitudes scores over and above that attributable to either the home or peer environment" (p. 1905). The traditions of learning environments research provide a common language and promising methods to meet the new challenges facing educators and researchers in science and education in a technology-rich world. The literature resoundingly states that the crucial component of teaching and learning is the teacher and his/her pedagogical approaches. Fortunately, these ISLE studies and other similar investigations indicate that today's university and school teachers are making a positive difference in science education.

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Chapter 84
Using a Learning Environment Perspective in Evaluating an Innovative Science Course for Prospective Elementary Teachers

Catherine Martin-Dunlop and Barry J. Fraser

Introduction and Overview

Evaluating innovative curricula and teaching strategies can be economically and effectively accomplished using reliable and valid surveys that are central to the field of learning environments. In the past, traditionally, evaluation's main role at the university level has been instructor accountability, with evaluation information seldom being used to improve instruction. The focus of this chapter is the use of learning environment assessments in the evaluation of a science course for prospective elementary teachers.

There is a rich history of studies that have employed a learning perspective in the evaluation of science programmes at the school level. Following Herbert Walberg and Gary Anderson's (1968) pioneering evaluation of Harvard Project Physics in the USA, many other researchers have used the various learning environment questionnaires described in Fraser's chapter in this Handbook in evaluating different innovative approaches to science teaching and learning at the elementary-school, middle-school and high-school levels. Examples of these evaluations include: Millard Lightburn and Barry Fraser's (2007) investigation of the use of anthropometric activities in high-school science in Florida; Stephen Wolf and Barry Fraser's (2008) study of inquiry-based laboratory activities among middle-school students in New York; Linda Scott Houston et al.'s (2008) evaluation of elementary science kits in Texas; Dorit Maor and Barry Fraser's (1996) evaluation of inquiry-based computer-assisted learning among 221 high-school students in Western Australia; and Maria Peiro and Barry Fraser's (2008) investigation of a 3-month intervention among early childhood students in Florida.

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The number of learning environment studies that have focused on science courses as part of teacher education programmes is somewhat limited. Staff in such programmes must not only teach science content to prospective or pre-service teachers, but also consider that their students might currently be teaching themselves, or soon will be. "Unlike most professions, students in education programs arrive with significant experience (12–15 years) in watching 'experts' in action. This 'apprenticeship of observation' means that teacher candidates enter the university with significant preconceptions about what it means to be an effective teacher and a learner" (Rachel Harrington and Larry Enochs 2009, p. 45).

Reforming undergraduate science laboratory courses, particularly for non-science majors, must continue if we want to develop scientifically literate citizens who enjoy and appreciate science. For example, an increasing number of the courses that have been specifically designed, or redesigned, for prospective elementary teachers include the goals of improving attitudes towards science, increasing understanding of the nature of science, and recognising the important role of science in our everyday lives. It is desirable that courses for prospective elementary teachers have less emphasis on rote memorisation of vocabulary, mathematical abstraction, textbook questions and canned or cookbook laboratory experiments. Instead, they should include more guided, open-ended inquiry investigations. Without a positive experience in a science laboratory course, many future elementary teachers will avoid teaching science altogether or relegate it to the 'back burner' – especially with current pressures in many countries to improve standardised test scores in reading and mathematics. Unfortunately, many elementary teachers tend to teach science in the same didactic style which they commonly experienced during their own education.

The next section reviews past science classroom environment studies that have involved teacher education programmes that take place in university settings. Although most of the programmes reviewed below were for prospective or pre-service teachers, some of the science learning environment studies considered below focused on in-service teachers involved in professional development.

Following this review of past studies, we report an evaluative study based on the course, A Process Approach to Science. In addition to our research being unique in the learning environments field because it involved higher education students (an overlooked population of participants), it followed the trend within the field of combining quantitative and qualitative data-gathering approaches in order to provide multi-layer perspectives (Fraser and Tobin 1991; Tobin and Fraser 1998).

Learning Environments in Teacher Education Programmes

One of the first learning environment studies to tackle the challenges inherent in teacher preparation was conducted by Allan Yarrow et al. (1997). They used the College and University Classroom Environment Inventory – CUCEI (Fraser et al. 1986) in an attempt to narrow the gap between students' actual and preferred or ideal perceptions of the university classroom environment. Their sample consisted of 117 pre-service primary teachers in six classes in Australia. A five-step approach was used to improve the environment of the university teacher education classes, as well as the school classroom environments of these prospective teachers during their practice teaching (using the My Class Inventory – MCI; Fisher and Fraser 1981). Although the university classes were not designed around school science curriculum, many of the findings can be generalised to pre-service teacher education classes that do specifically focus on the 'methods' of teaching science to young children. For example, some of the pre-service teachers' suggestions for improving their university classroom environment included less lecturing, fewer instructor-led activities, clarifying links between theory and practice, and having more hands-on group activities. Overall, Yarrow and colleagues showed that using an action research model within a university learning environment study holds considerable promise for developing reflective pre-service teachers.

In stark contrast to other countries, researchers in the Netherlands have a tradition of conducting science classroom environment research in teacher education. The Questionnaire on Teacher Interaction – QTI (Theo Wubbels et al. 1990) has been extensively used to assess interpersonal relationships between teachers and their students. Anne Holvast et al. (1993) investigated cooperating or master teachers' and pre-service teachers' interpersonal behaviours in 142 physics classrooms. When students in the pre-service teachers' classrooms completed the QTI at the end of a 4-month practicum, class means were calculated for each of the scales. In addition, all student teachers and a sub-sample of cooperating teachers completed two forms of the QTI – actual and ideal – to yield six sets of data on perceptions. The data were then analysed to see how the student teachers' performance was related to the cooperating teacher's way of teaching. Generally, student teachers' communication style was similar to that of their cooperating teacher, although correlations between high-school students' perceptions of student (pre-service) teachers and of their cooperating or regular teacher were not high. Jack Levy et al. (1992) found a stronger relationship between cooperating and student teachers' behaviour in American classrooms, probably because '…the grouped Dutch student teachers may be more independent from their cooperating teacher than their American counterparts who are placed individually' (Holvast et al. 1993, p. 143).

The Constructivist Learning Environment Survey (CLES), developed by Peter Taylor et al. (1997), has been employed in studies of teacher preparation programmes. John Cannon (1995) provided further validation of the CLES when used in a mid-sized western university in the USA with 43 pre-service elementary teachers during a science methods course. Bruce Johnson and Robert McClure (2004) used a shortened and revised version of the CLES with 290 elementary and secondary pre-service and in-service science teachers in Minnesota, USA, combined with data collected from classroom observations and teacher interviews. Teachers' classroom environment perceptions were compared to their students' perceptions and profiles were developed for each teacher. As found in previous research, teachers' perceptions were often more positive than their students. In cases where the magnitude of this difference is appreciable, it "…can provide the teacher with an impetus for change" (David Johnson and Robert McClure 2004, p. 74).

Rachel Harrington and Larry Enochs (2009) used the CLES to gauge the success of a 1-year teacher preparation programme for prospective secondary school mathematics or science teachers in Oregon, USA. Success was defined in terms of ‘conceptual coherence’ between courses that made up the program and among the types of pedagogical and assessment choices made by staff in the program. Harrington and Enochs emphasised that new evaluation tools are needed for teacher preparation programmes. Simple job placement rates and accreditation results historically used in the past provide an overly simplified picture. “A teacher preparation program that is truly attempting to improve and develop should reflect on and inquire into its own practice as a way to measure its success” (p. 46). When these researchers administered the CLES three times to 31 pre-service teachers and compared the resulting data with programme course syllabi and students’ reflective writing, they concluded that constructivist principles must be explicitly integrated into coursework and field experiences. In addition, Harrington and Enochs felt that the study’s results can be used to initiate reflective inquiry across the entire teacher preparation programme and not just for one or two subject areas.

Considerable classroom learning environment research has been undertaken in Asian countries. Heui Baik Kim and her colleagues used a Korean-language version of the Science Laboratory Environment Inventory – SLEI (Fraser et al. 1992) to compare perceptions of university students in different countries. Interestingly, prospective elementary teachers enrolled in a teachers’ college had far less favourable perceptions of their science laboratory environments than tertiary level students in other countries (Kim and Kim 1995).

In South Africa, Jill Aldridge, Barry Fraser and Sipho Ntuli used a translated IsiZulu language version of the What Is Happening In this Class? (WIHIC) to provide feedback to 31 in-service teachers undertaking a distance-education programme. By administering the actual and preferred forms of the WIHIC (Fraser et al. 1996) to their 1,077 primary school students, these teachers identified actual–preferred discrepancies and implemented a 12-week intervention in an attempt to overcome these discrepancies. Results supported the efficacy of teachers using learning environment assessments to guide improvements in teaching practices.

Rebekah Nix and colleagues used a version of the CLES in two different studies in Texas involving the evaluation of the implementation of an innovative teacher professional development programme called the Integrated Science Learning Environment (ISLE). In these studies, the professional development programme was evaluated in terms of teachers’ classroom behaviour, as assessed by their middle-school students’ perceptions of their classroom learning environment. Rebekah Nix et al.’s (2005) study involved a sample of 12 teachers who administered the CLES to 1,079 students in 59 classes. The second study’s sample consisted of 17 teachers and their 845 students (Nix and Fraser 2011). Overall, changes in the teachers’ professional development environment appeared to foster positive changes in their school classroom environments.

An Innovative Science Laboratory Course for Prospective Elementary Teachers

At a university in California, all fourth-year students who are Liberal Studies majors must enroll in A Process Approach to Science (250–300 students every year). Students usually take this course before beginning a teacher education programme. The course is not a 'methods' course and is taught in a hybrid classroom that also serves as a laboratory. The same instructor delivers the mini-lectures, leads whole-class discussions in a seminar style, and arranges guided-inquiry activities (Colburn 2000) for small-group cooperative learning. Class size is small, with a range from 14 to 32 students and an average of 24.5 students. Inquiry activities are based around content that includes basic scientific principles and concepts reiterated from earlier courses in the physical, life and earth sciences. A self-directed, experimental design investigation spans much of the course. Course objectives include students (1) liking science, (2) better understanding the nature of science and what actual scientists do and (3) developing their ability to identify, define and solve problems like scientists do.

Three science laboratory courses (12 units) serve as prerequisites for the course. Unfortunately, many students struggle through the prerequisites. When they take A Process Approach to Science with instructors in the Science Education Department (housed within the College of Natural Sciences and Mathematics), students often dislike science and they have little confidence in their ability to do well in science or to adequately teach the subject to elementary-school children.

Purpose of Study

The purpose of our study was to evaluate the overall impact of the course A Process Approach to Science based on students' perceptions of the learning environment and attitudes towards science. Further, we wanted to identify the benefits of having a science course specifically designed for prospective elementary teachers, as this rarely has been investigated in the past. Consequently, we collected data about students' perceptions of the learning environment and attitudes towards science based on their *previous* laboratory course (usually one of the more traditional prerequisite courses) and compared these to data collected at the conclusion of A Process Approach to Science. We also explored associations between the learning environment of A Process Approach to Science and the student attitudes, following a strong tradition in prior research (Fraser 1998, 2007), and, finally, transcribed and analysed oral responses from 35 students in two classes to interview questions in order to generate more in-depth and nuanced perspectives about course effects.

Research Methods

The participants consisted of 525 female prospective elementary teachers from 27 classes enrolled in the course over four semesters in 2002 and 2003. The average age of the students was approximately 24 years, with a median age of 23 years, and a range from 20 to 52 years.

The seven part-time and full-time instructors who taught the course followed a similar syllabus. All instructors had considerable K–12 science teaching experience, with an average of 10.3 years of experience. The first author was a participant-observer (Arsenault and Anderson 1998) and taught six of the 27 classes (22%).

The instrument that we used to assess the learning environment mainly consisted of the scales of Student Cohesiveness, Instructor Support, Investigation and Cooperation selected from the What Is Happening In this Class? – WIHIC (Fraser et al. 1996). In addition, we included the Open-Endedness and Material Environment scales from the Science Laboratory Environment Inventory – SLEI (Fraser et al. 1992). Finally, we used the Enjoyment of Science Lessons scale from the Test of Science-Related Attitudes – TOSRA (Fraser 1981) to assess student attitudes. In total, the survey contained 54 items with five frequency responses (Almost Never, Seldom, Sometimes, Often and Very Often).

In addition, a separate set of questions exploring four thematic areas was formulated for use during a semi-structured interview with a subgroup of 35 participants. These questions tapped into students' reactions to open-ended inquiry, cooperative learning, and opportunities to improve the learning environments of pre-service science teachers.

The quantitative data collected were subjected to a range of statistical analyses. To validate the modified survey, factor analysis was conducted separately for data for previous laboratory classes and for A Process Approach to Science. Internal consistency reliability and ability to differentiate between classrooms (one-way ANOVA) also were determined. To investigate differences between the previous course and A Process Approach to Science, we used effect sizes (Cohen 1998) to indicate their magnitude and *t*-tests to determine their statistical significance. Because conducting multiple *t*-tests can lead to Type I errors, a modified Bonferroni procedure was used as well (Jaccard and Wan 1996). The Bonferroni procedure ensures that statistical testing is not compromised by sample size or by the number of tests performed. Using this procedure, t values are first ranked from most significant to least significant (lowest to highest p value). The most significant p-value is divided by the total number of tests performed (n). If the resulting p-value is less than the desired alpha (i.e. 0.01), the difference is still considered significant. The second difference is considered significant if the resulting p-value is less than the desired alpha after dividing by n-1. This procedure is continued for each successive p-value by dividing by $n–k$ until a statistically non-significant result is obtained. Lastly, associations between the learning environment and attitudes towards science were investigated using simple correlation and multiple regression analyses.

Table 84.1 Average item mean, average item standard deviation, and difference (effect size and *t*-test for paired samples) for previous laboratory course and A Process Approach to Science for each learning environment and attitude scale

	Average item mean		Average item Standard deviation		Difference	
Scale	Previous Lab Course	A Process Approach to Science	Previous Lab Course	A Process Approach to Science	Effect Size	*t*
Learning Environment						
Student cohesiveness	4.13	4.44	0.20	0.21	1.51	7.32**
Instructor support	3.26	4.20	0.23	0.40	2.98	12.91**
Investigation	3.43	4.41	0.30	0.22	3.77	15.97**
Cooperation	4.39	4.72	0.17	0.16	2.00	7.78**
Open-endedness	2.30	3.85	0.24	0.22	6.74	34.54**
Material environment	3.77	4.40	0.16	0.17	3.82	15.20**
Attitude						
Enjoyment of science lessons	3.09	4.06	0.27	0.38	2.98	15.06**

** $p < 0.01$ (Using modified Bonferroni procedure with 7 tests)
The response key was: 1 = Almost Never, 2 = Seldom, 3 = Sometimes, 4 = Often, 5 = Almost Always.
$N = 525$ female prospective elementary teachers in 27 classes

Data from the interview responses were transcribed and then examined using an analytical inductive process (Bogdan and Biklen 1992). This approach reviews information with an assertion, question or theme in mind, and then revisions are made until a particular pattern, or patterns, emerges (Erickson 1998). In this particular case, four key themes framed the analysis.

Findings from Questionnaire Data

Principal axis factor analysis confirmed that the majority of items belonged to one of the six a priori scales extracted from the WIHIC and the SLEI with eigenvalues above unity. Forty-three out of 46 items had loadings above 0.40 on their own scale and no other scale. Therefore, these 43 items were used to determine internal consistency reliability and ability to differentiate between classrooms (ANOVA). Cronbach alpha coefficients were high for two units of analysis (students and classes) and ranged from 0.67 for Cooperation to 0.98 for Instructor Support. Reliability for the attitude scale was also high and ranged from 0.93 to 0.98 (Catherine Martin-Dunlop and Barry Fraser 2007).

Table 84.1 shows that prospective elementary teachers generally rated their previous laboratory courses as having a positive learning environment, with the

Table 84.2 Simple correlation and multiple regression analyses for associations between the learning environment and attitudes towards science using two units of analysis

Scale	Unit of Analysis	Attitude-Learning Environment Association	
		r	*ß*
Student cohesiveness	Individual	0.17**	–0.06
	Class	0.04	–0.10
Instructor support	Individual	0.61**	0.51**
	Class	0.75**	0.87**
Investigation	Individual	0.35**	0.07
	Class	0.18	0.08
Cooperation	Individual	0.22**	–0.01
	Class	0.32	–0.14
Open-endedness	Individual	0.36**	0.12**
	Class	0.28	–0.22
Material environment	Individual	0.34**	0.20**
	Class	0.44*	0.26
Multiple correlation (*R*)	Individual		0.66**
	Class		0.82**

*$p < 0.05$, **$p < 0.01$
$N = 525$ female prospective elementary teachers in 27 classes

exception of Open-Endedness whose mean was 2.30 (i.e. these courses *seldom* had divergent experiments or investigations, or *seldom* allowed students to pursue their own science interests). Despite these relatively positive results for previous laboratory courses, dramatically higher scores were observed for A Process Approach to Science for all learning environment and attitude scales (see Table 84.1).

Jacob Cohen (1998) considers that effect sizes of 0.10 and less are small, of 0.25 are moderate and 0.40 and above are large. Consequently, according to Table 84.1, effect sizes for between-course differences were unusually large for all learning environment scales with values ranging from 1.51 standard deviations for Student Cohesiveness to 6.74 standard deviations for Open-Endedness (although when using the class mean as the unit of analysis, standard deviations are small, resulting in large effect sizes). For Enjoyment of Science Lessons, the difference between previous laboratory classes and A Process Approach to Science had an effect size of 2.98 standard deviations. Table 84.1 also indicates that the *t*-test results were statistically significant for all scales ($p < 0.01$) even when using the modified Bonferroni procedure.

Associations between the Enjoyment scale and learning environment scales were investigated using simple correlation and multiple regression analyses. The results are reported in Table 84.2. All associations were statistically significant using the individual as the unit of analysis. With the class mean as the unit of analysis, the scales of Instructor Support and Material Environment were significantly correlated ($p < 0.01$) with Enjoyment of Science Lessons. For each unit of analysis, the simple correlation with Enjoyment of Science Lessons was highest for the learning environment scale of Instructor Support.

The multiple regression analysis showed that the joint association between the set of six learning environment variables and attitudes towards science was statistically significant for both units of analysis. Standardised regression weights in Table 84.2 indicate that, for the individual unit of analysis, Instructor Support had the strongest independent association ($\beta = 0.51$; $p < 0.01$) with attitudes, although Open-Endedness and Material Environment were also statistically significant independent predictors. Using the class mean as the unit of analysis, Instructor Support again was a significant independent predictor of Enjoyment of Science Lessons ($\beta = 0.87$; $p < 0.01$).

Findings from Interview Data

Four themes emerged from the analysis of the interview responses. The first and foremost theme focused on the lack of open-endedness in prior science courses compared with A Process Approach to Science. A second theme that emerged pointed to student groups not always automatically leading to class cohesion or cooperation. The third theme focused on the appropriate balance in open-ended learning environments. The fourth theme related to changes in attitudes towards science. In the following paragraphs, we discuss each of these themes using selected student responses.

We gave the first theme the title of 'The Abyss Between Previous Laboratory Courses and A Process Approach to Science'. Students were asked: "What was the biggest difference between your previous science laboratory class and this class?" A typical and thoughtful student response follows:

> We had a laboratory once a week and in my laboratory class it was totally a convergent way of thinking–the directions were all on the board the second we walked in. I was wondering what was the point of me doing this if everybody already knows the answer. So I found myself speeding through it just to get it done so that I could get out of there. This class was very divergent. We were given our experiment but we weren't told how to do it, we weren't told an order, we weren't told what we should come up with at the end. It was basically here you go, have fun, tell me what you think and then describe the processes.

This response strongly supports the results emerging from the quantitative data that indicated that the biggest difference between students' previous laboratory course and A Process Approach to Science was related to Open-Endedness. In almost every interview, students talked about how their previous laboratory classes had preset directions or procedures, were convergent with everyone getting the same answer to experiments and investigations, had a dearth of hands-on activities, had little connection between material covered in lectures and laboratory activities, and had content that was not relevant to their lives or their future careers as elementary-school teachers. These voices from female prospective elementary teachers were clearly saying what many science educators have been advocating for a long time, namely, that science content courses should be specifically designed for future elementary teachers.

The second notable theme to emerge was labeled 'Student Grouping Isn't the Same as Student Cohesion or Cooperation'. In this case, the question asked was: "Did you have cooperative learning groups in your previous science laboratory course? (If yes…) How did the cooperative learning experience in this course compare with your previous science laboratory course?" A representative response follows:

> They gave us exactly what they wanted us to do and we just broke it up. We never really did it as a group. It was more like, I'll do this part, you do this part, and we'll get together at the end. But in [this class] we actually worked together on everything as a group. Whatever I didn't understand, somebody helped me to understand and so we helped each other. In our class, we're kind of friends now, and we still talk out of class, and it's really nice but different.

This prospective elementary teacher seemed to understand the difference between cooperative learning and just being in a group. Spencer Kagan and Miguel Kagan (1992) emphasise that true cooperative learning must have positive interdependence, simultaneous interaction and equal participation, but this point is not understood by many instructors at all levels. In previous laboratory classes, students mentioned rushing through activities in order to get out of class as quickly as possible, as well as breaking up work into smaller parts. Little discussion synthesised the material that the group was trying to understand. Particularly illuminating was a statement from another student: "In [this class], it was different…a different environment…it was more comfortable to learn."

The third theme was titled 'Guided-Open Endedness – The Goldilocks Zone'. Borrowing from Richard Dawkins (2008) and Bill Bryson (2004), the term 'Goldilocks zone' is highly appropriate for summarising what students said that they needed to maximise their learning. The question posed was: "Would you have preferred more, less or the same level of open-endedness in this course? Can you explain why you feel this way? How did the level of open-endedness in your previous science laboratory course compare with this course?" After students had been shown some items from the SLEI dealing with Open-Endedness, all students said that they preferred the same level of open-endedness in the course. The following quote is typical:

> You know that's a tough question for me because most of my prior classes didn't have any open-endedness. So I felt as if there was quite a bit. Was it too much? I don't think that it was too much. Could there have been more? Very possibly there could have been but, because I haven't been exposed to it, it's hard for me to say. I really, really like the fact that we did have as much open-endedness because I felt as if I had a personal stake in it. I extended my own learning because I wanted to, and because I wanted to get as much as I could out of it.

Surprisingly, despite many of the students' earlier feelings of fear and anxiety about learning science, they all still preferred less structured activities, divergent experiments and investigations, and choosing their own questions and procedures. It is thought-provoking that these prospective elementary-school teachers mentioned the importance of balance. Instructors in the course try to avoid traditional 'canned' experiments and investigations, or what Allan Colburn (2000) calls 'structured inquiry', in which instructors provide hands-on problems to investigate, the procedures and the materials, but do not inform students of expected outcomes. Campbell McRobbie and Barry Fraser (1993) found that Open-Endedness was significantly and negatively associated with some scales on the Test of Science-Related Attitudes, but we do not know what level of open-endedness the participants were experiencing. As good instructors know, “All learning involves risk. Yet, to take the leap of risk as a learner…there must not only be a safe and predictable learning environment, but also the learner must have a sense of entitlement, an audacity” (Erickson 1998, p. 1157). Instructors who teach the course predominantly use ‘guided-inquiry’ for which the materials and topic or problem are provided, but the students devise their own procedures and are encouraged to find multiple solutions to the same problem.

The fourth theme was simply called ‘Attitudes Towards Science’ and was driven by the last set of interview questions: “Would you say that your attitude towards science has stayed the same, improved or declined as a result of taking this course? Can you describe what factors have contributed to this change?” The main purpose in asking this question was to support or refute the quantitative findings derived from using the Enjoyment of Science Lessons scale (e.g. Instructor Support being the single strongest independent predictor of positive attitudes).

All but one of the 35 students interviewed said that her attitude had improved as a result of taking the course. One student said that her attitude had stayed the same because she already had a positive attitude even before the course began. Factors that contributed to improving attitudes towards science covered an array of things. Below is a typical quotation that neatly summarises the overall consensus of interviewees about their attitudes and ties in with the quantitative data:

> I would say definitely improved. I feel a lot more confident that, when I have a classroom, I’ll be able to integrate science into it without using an extreme amount of time, effort or money. I also think that science helps kids across the board working on those processes. I think they are needed for all subjects. It can help them to be better learners and students, I think. [Researcher: “What do you mean by across the board?”] I think of the processes of making inferences and using our prior knowledge. Those are the things that they can use in reading comprehension or math or anything. I think science is a really good way to teach those processes and, at the same time, teach the science content that they need.

Although the interview questions did not specifically address each of the survey’s learning environment scales, aspects of all six scales manifested themselves in the prospective elementary teachers’ responses. The most striking finding was that interview responses strongly supported the survey’s finding that the biggest difference between students’ previous laboratory class and A Process Approach to Science was the degree of Open-Endedness.

Conclusion

Although the majority of past learning environment research in science education has involved K–12 students in schools, our study is distinctive in that it involved university student who were studying to become elementary-school teachers.

In particular, it focused on an innovative university science content course for prospective teachers.

Our course evaluation involving the use of a learning environment questionnaire with 525 students provided tangible and specific information about the course's overall success, as well as about factors that seemed to contribute to its effectiveness. Relative to a comparison group, students undertaking the innovative course perceived much higher levels of classroom cohesiveness, instructor support, investigation, cooperation, open-endedness and material environment and enjoyed the course more (with effect sizes ranging from 1.5 to 6.7 standard deviations).

As well, our study included qualitative methods based on semi-structured interviews with a subgroup of 35 students. Four themes emerged related to: the lack of open-endedness in prior science courses compared with the innovative course; student groups not always automatically leading to class cohesion or cooperation; the appropriate balance in open-ended learning environments; and changes in attitudes towards science.

The course that was the focus for our study could provide a model for other teacher education programs. Inquiry-based approaches to teaching and learning are valuable in undergraduate science content courses, and therefore should not be reserved for science 'methods' courses. Teacher education students need to see their science professors teaching in a constructivist and inquiry-based manner.

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Chapter 85
Evolving Learning Designs and Emerging Technologies

Donna DeGennaro

Recent efforts have focused on how best to design learning environments that engage students in ways that emulate the activities of practicing scientists (NSTA 2003). An integral aspect of scientists' practices includes the use of various technologies. In the profession, technology acts as a tool to support the processes by which scientists perform inquiry, carry out investigations, collect data, and execute analysis. Although productivity tools, such as spreadsheets and word processors exists as a support for the teaching and learning of science, the last several decades have introduced many emerging technologies into classrooms. These include visualizations, animations, and simulations to name a few. Each of these tools provides insight into learning designs that actively immerse students in roles that reflect those of scientists. What is more, it becomes evident that these evolving learning designs alter the roles of teachers and learners. New roles ultimately offer students a more authentic and self-directed learning experience in science classrooms. Together, the trends in science education, learning designs, and the use of technology bring about unique possibilities for the support teaching and learning of science education.

This chapter presents emerging technologies and their association with evolving learning designs. To begin, I first overview the skills and dispositions projected as being crucial to science education. Following this, I offer a definition of and research trends in learning environments to assist in framing how the trends reflect the most recent research on effectively engaging students in learning science. Within this section, I present examples of technology-mediated learning environments and their interconnectedness to the design of learning experience in science education. I conclude by providing an overview of the trends and offering implications for future designs.

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Trends in Science Education

The major research and science organizations have offered their perspective on what it means to become scientifically literate. Namely, these organizations have generated a comprehensive array of skills and dispositions that are important for both scientific literacy (AAAS 1993) and twenty-first-century learning (The Partnership for 21st Century Learning, 2004). These two concepts suitably converge as a foundational grounding to commence our thinking about designing effective learning environments for science education.

To begin, science literacy is defined by several broad components. In addition to having basic factual knowledge, students should acquire the ability to understand issues of daily scientific events found in news. An example of this might be the governmental debate around global warming. Another factor of scientific literacy is gaining an appreciation for the natural and scientific world. Part of science literacy then, is having the ability to make informed personal decisions based upon appreciating how natural laws of science influence one's life (Hazen 2002). Collectively, these components focus on the overarching importance of scientific concepts rather than a focus on discrete facts and skills often associated with the teaching and learning of this discipline.

Similarly, twenty-first-century skills include factual knowledge as well as applicable real-world skills. In the discipline of science these inevitably include content knowledge. However, content knowledge is not isolated; rather it is seen as embedded in pedagogical models such as problem-based learning, cooperative learning, and real-world contexts. The assertion is that these models offer the most effective learning designs for science education because they place students in the center of scientific practices. For example, students' employment of creativity, innovation, critical thinking, problem solving, communication, and collaboration is intertwined within the learning design. These skills are fostered as students create research questions, develop theories, use and offer reliable explanations, and make accurate predictions. In carefully crafted learning designs, students also engage in an iterative process of building theories, asking questions, investigating, reasoning, and predicting (NRC 1996; AAAS 1993). Further, students work closely and interactively with others to inform their thinking. Experts who have crafted the twenty-first-century skills model have also projected that students should be utilizing technology as part of their learning process and as a result gain numerous technology-related skills. These include information literacy, media literacy, and ICT literacy (The Partnership for 21st Century Learning 2004). The twenty-first-century model expands the construct of scientific literacy by providing a comprehensive picture of the complex nature of becoming literate in this discipline.

While a listing of skills along with an implied implementation of how they become cultivated is helpful, it falls short of illuminating a clear picture of how science and technology come together to foster scientific knowledge and practice. Too often technology has been viewed in education as a tool or a supplement to learning (Varma et al. 2008). Scientists, however, utilize emerging technologies as an interconnected part of their work. Research offers a more integral picture of what this might look like (Sawyer 2006). To begin this conversation, I expand the notion of learning design drawing from the learning sciences perspective. This serves as a backdrop to frame the research trends supporting how emerging technologies have become an inseparable and supportive part of the teaching and learning of science.

Learning Designs

The Learning Sciences is a field dedicated to the research and development of pedagogical, technological, and social policy innovations. The aim of researchers in this field is to study the design, implementation, and evolution of designed learning environments with a goal of improving education. The focus has traditionally been on the role of social context, cognition, and design in learning. More recently, centers such as LIFE (Learning in Informal and Formal Environments) have included development, psychology, neurobiology, and sociocultural disciplines to help inform our understanding of learning. Much of the research in this field is conducted in and around how technology supports the learning of science.

The learning scientists' commitment of examining how technologies supports science learning comes, to some degree, from the realization that professions today find their work entails interpreting and accessing multiple forms and representations of information. Information presents itself through visualizations, text, numbers, images, and other graphical forms. As scientists work, they are continuously moving back and forth between different kinds of information formats to create research questions, inquire, analyze and interpret data, and make new conjectures for further study. They are also connected to a broad community of other scientists who share information and co-construct knowledge and ideas. This suggests that scientists will inevitably cross multiple boundaries of practices – across people, tools, and "texts." We can then envision that scientists are continuously in practice with various resources around them, including working in and across the technology.

In order to inform the design of learning environments, the learning sciences group has developed new research frameworks and methods to examine the multidimensional view of learning and technology within learning designs. Namely, learning scientists employ Design Experiments (Brown 1992) and Design Research (Barab 2006; Cobb et al. 2003). Analysis is focused on the orchestration of and relation between expected tasks, encouraged discourses, established norms, used tools and materials across multiple contexts. The cross-examination of the findings across local contexts informs effective design principles (Cobb et al. 2003). The research involves the voice and contribution of all participants connected to the learning environment including teachers, students, researchers, and designers.

These frameworks have been criticized for not including or attending to particular aspects of the learning structure. Specifically, aspects often absent from the research include beliefs about learning and knowledge, learning activities and participant structures, configurations of both physical and virtual spaces (Bielaczyc 2006).

With this, it is critical to examine not only the learning design outcomes, but also how the social and technical aspects of the learning design. Specifically, when students use technologies, their social participation and technology use dialectically, rather than causally, create activity (Lenk 1997). *Social* refers to the people. In particular, social is the knowledge, skills, attitudes, values, and needs people bring to the environment. *Technical* comprises of tools, devices, and techniques needed to support the transformation of inputs to outputs (Coakes 2002). The social and the technical systems act together to create the structure (Trist and Bamforth 1951) – the learning structure in this case.

In what follows, I offer learning design themes with embedded emerging technologies. Within these themes, I provide several evolving examples that suggest how the social and technical aspects of the learning designs support science practice. The examination of technology-mediated learning designs as a means of fostering scientific proficiencies affords opportunities for teachers and students to learn in concert with human and material resources in unique ways.

Collaboration and Knowledge Building

For many years, the technologies have supported scientific collaboration and knowledge building. These forms of participation have been a long embedded part of scientific work. As early as 1969, scientists have been connecting with others through the Internet to tap their knowledge and expertise. The connections have been crucial to scientific progress, as complex investigations of scientific questions require the expertise of more than one person. Following this model, educational designers have taken advantage of this flexibility and connectability of electronic mediums to allow students to learn in ways that are similar to those of practicing scientists. Today, Web 2.0 technologies make knowledge construction and building even more seamless and simple. The following designs provide early illustrations of how web-based tools afford the organization and sharing of information to support collaboration and knowledge building.

An early attempt at collaborative software took advantage of premature Internet communications technologies such as email and newgroups. The Collaboratory Notebook (Edelson et al. 1996) was modeled loosely on the notion of a scientist's notebook. It was part of a larger research project called CoVis (Gomez et al. 1998). Designed to support collaborative learning models, students worked with team members to post questions, share databases with team members, and have access to remote mentors (telementors). Among other scientific practices, this design model fosters collaboration and communications skills not only with students but also with real scientists. Studies found that this model was an accessible design to support iterative practices such as giving students opportunities to post, refine, and quickly receive feedback on the ongoing scientific process (Edelson et al. 1996). Although, access to telementors was difficult to sustain, the connection to real scientists gave students insights into how real scientists work and think (O'Neill et al. 1996).

Design experiments and test bed research examining this design were used not only to see the ways in which teachers and students used them, but also how they would diversely and effectively integrate into classroom learning (Gomez et al. 1998). This effective integration encompasses the opportunities for distributed knowledge through technical supports of the discussion posts, databases, and remote access.

Another example of an innovation that draws on Internet connectivity is CSILE (Computer Supported Intentional Learning Environments). CSILE is a web-based tool designed for students to interact with each other across a communal database. This online database has both text and graphic capabilities. The learning design is grounded in both a collaborative and problem-based learning. It also draws upon a Knowledge Building Environments philosophy (Scardamalia and Bereiter 2006). Knowledge Building Environments is grounded in the belief that discourse is a primary part of learning science. More specifically, it is "discourse whose aim is progress in the state of knowledge: idea improvement" (Scardamalia and Bereiter 2006, p. 102). The commitment is to engage students in collaboratively solving a proposed problem where the students learning progresses through communal collaborations. The concept is that the ongoing discussions both drawn from the databases yields common understanding and expands the base of accepted facts by that community. CSILE's multi-window networked learning environment affords students the opportunity to work across resources (computer tools, textual and graphical resources, peers, and teachers) in order to build an understanding of scientific topics. As students work with their peers, receive guidance from the teacher, and access scientific content, they are socially constructing knowledge (Scardamalia and Bereiter 1993) similar to how scientists do. One of the key successes of knowledge building in platforms such as CSILE is that through accessing multiple forms of information with and through the technology students become a legitimate part of building knowledge together as they move in and out of core and peripheral participation (Lave and Wenger 1991). CSILE supports technical and social integration to potentially "restructure the flow of information in the classroom" (Scardamalia and Bereiter 2006, p. 104) as all participants use the technology to consult on questions, ideas, criticisms, and suggestions in a public space.

One collaborative discussion model that utilizes the affordances of the Internet is Kids as Global Scientists (KGS). The learning design is based on research suggesting that student-negotiated conversations foster insight into their own knowledge (Brown and Campione 1994). KGS integrates this philosophy with an inquiry-based science model that allows geographical dispersed participants (teachers, students, and parents) to view the same data. The activity centers on investigating weather and climate concepts in one's city. The medium also supports collaboration between students and science experts around real-time and archived weather and species datasets. In these programs, participants use the same weather data from the Internet, along with archival weather data to develop questions around the affects and influences of weather in their hometowns and across the world. Similar to the previous examples are using technical tools to formulate scientific understands and work with peers and experts to formulate questions. This process is ongoing and occurs across technologies and people.

Co-constructing Scientific Processes

Scientists are continually immersed in trying to form understandings of real-world situations. That is, they are researching current environmental phenomena for which they are attempting to find solutions. As a result, they need to be in a constant cycle of developing hypotheses, designing experiments, arguing theories, and testing solutions. This cyclical practice is not completed in isolation, nor is it done without the aid of technological tools. Various technology-enhanced learning designs have placed students in scenarios that reproduce the collective practices of developing scientific processes.

For example, Biology Guided Inquiry Learning Environment (BGuILE) utilizes an inquiry-based learning model to immerse students in the midst of a scientific mystery (Sandoval and Reiser 2004). Students are presented with the fact that an inordinate number of finches in the Galapagos Islands have died during a drought. The learning goal is to gain a better understanding of popular genetics. With this goal in mind, students enter the scenario in order to solve the problem through analysis of extensive data collected and organized by real genetic scientists. While students are not collecting their own data, they are acting as scientists would when brought in as experts together to examine a problem. The students are traversing social and technical spaces by accessing authentic data and conferring with their peers to make inferences. That process of scientifically and socially constructing knowledge is made visible within a tool called Explanation Constructor. This tool prompts students to scaffold their argument-making skills. Specifically, it acts as a guide to ensure that students are engaged in a real-world scientific process of problem solving. Researchers, however, have found that interacting with these environments may not be enough to help students develop understandings and ways of communicating that are consistent with scientific views. A socio-technical system of learning needs to combine both virtual and face-to-face interactions. A balance of technically mediated learning and offline small and whole-group learning structures provide a more comprehensive and supportive learning design (Tabak and Reiser 1997). This finding emphasizes that the technology itself is not central to the design, but rather an interconnected part of the larger learning environment.

Web-based Inquiry Science Environment (WISE), a free online learning environment for students in grades 5–12, is another platform that places students in the center of a problem. The WISE online database offers numerous previously designed inquiry questions from which teachers can choose. Some topics include genetically modified foods, earthquake prediction, the deformed frog mystery, and global warming. Once teachers choose an activity, students are guided through an inquiry process in order to ultimately take a position on the problem. The learning design is based on a model called SKI (Scaffolded Knowledge Integration). In this model, it is believed that inquiry must help make thinking visible, provide social supports, make science accessible, and promote autonomy for lifelong science learning (William 2008). Each learning activity begins by engaging students in questions that assist teachers in ascertaining what previous knowledge students bring to the assigned topic. After students reflect upon their current understandings, they are immediately connected to learning about and responding to a contemporary scientific controversy. Throughout the activity, students are continually evaluating information from predetermined websites and recording that information in an online journal. WISE has embedded tools that provide organizational supports for online investigations that model scientific processes. These tools scaffold student's investigations, development of inquiry questions, note taking, evidence gathering, information sharing, and knowledge display (William 2008). In closing the experience, students review the information they saved within these tools, color-code themes from the data, and construct an argument based on these themes in order to design debates to support their position. WISE designs advocate a carefully balanced combination of interactions between online and offline activities. The visibility of thinking in person and through the technology equally provides teachers with ongoing insights into how students are engaging in scientific practice. Further, this immediate visibility affords teachers an opportunity to intervene immediately when misconceptions materialize or practices need to be enhanced.

An alternative example of co-constructing scientific processes is evident in Learning by Design (LBD) (Kolodner 1997, 2006). LBD draws upon case-based reasoning (Schank 1982) to situate students in generating design skills, research skills, collaboration, and record-keeping skills. LBD is designed to orchestrate an iterative process of developing a hypothesis, designing an experiment and implementing that experiment. The expectation is that students learn by attempting to achieve design challenges. The design process promotes reflection on the experience needed to learn productively from this experience. SIMLE (Kolodner 2006) is a technology innovation used to assist in the fostering and support of the learning process. During the implementation of their design, students write their experiences into a Design Diary page, which later translates to an online case library for others to use. The Design Diary page scaffolds learners by providing prompts as students create designs, run experiments, and collect data. At designated points within the process, students share their data and data interpretations through poster presentations. In the process of planning, design, implementation, and redesign, students make changes based upon feedback from their presentations. This design has suggested that learners are given the opportunity to try again, often several times. Through working across technological supports and interactions with their classmates, students continuously create, revise, and recreate their designs to work toward better solutions (Kolodner 2006). The design elements cultivate a disposition of iterative processes so that students understand that scientific work is ongoing. Solutions do not present themselves upon the first try. Studies of LBD have indicated that students rely on both social and technical activities to build understandings, apply what they learn, and get real-time feedback. Yet research suggests that new iterations of LBD should place more emphasis on the in-person social aspects of the design. Learning designs must include scaffolds that equally rely on the interrelationship of social and technical interactions in the problem-solving process.

Maneuvering Visualizations

Creating and maneuvering visualizations is necessary for the development for scientific knowledge. Scientists use technology to support the creation of multidimensional visualizations with or without animation abilities. Scientists create and use visualizations to assist them in "seeing," testing, and revealing aspects of scientific phenomenon that is often impossible because of its infinitesimally small-scale or inaccessible real-life recreation. Several examples of visualization have been applied in science classrooms. The following are a few of the technology-enhanced learning designs that utilize visualization to replicate how scientists might use visualizations to test ideas, uncover scientific events, gain insights to develop new schemes, and illustrate ideas that cannot be described verbally.

WorldWatcher is used in education as a supportive scientific visualization environment for the investigation of scientific data (Edelson et al. 1999). Researchers and designers first introduced it into classrooms in April of 1996. WorldWatcher engages students in authentic practice (Edelson and Reiser 2006) by providing an accessible and supportive environment for students to explore, create, and analyze scientific data. Its goal is to allow students to have access to the same features found in the powerful, general-purpose visualization environments that scientists use. The visualization platform equips students with the support they require to learn through the use of the tools. WorldWatcher promotes distributed cognition and participant role dispersal. Student engagement in expert practice and teamwork affords the ability to link the manipulability of features and connection to data so that teams can make decisions about scientific processes, just as experts do (Gordin et al. 1994).

Another visualization environment, Chemation, is an animation tool that allows learners to build molecular models and animations of chemical phenomena. Researchers analyzed Chemation's ability to support practices of student learning including designing, interpreting and evaluating animations. They examined the impact of the practices on student understanding including the development of content knowledge. The results of research show that the learning design is best structured as including a combination of instructional practices. These include designing, interpreting, and evaluating animations. In this way students are working across virtual and real spaces to maneuver aspects of the visualization, talk about their analysis of the phenomenon, and question the animation's validity. Viewing and interpreting animations were found to be least helpful. Students designing and creating their own animations have the greatest effect (Chang et al. 2007). Without the attention to fact checking with and distribution of ideas across peers, designing and interpreting animations do not sufficiently support understanding content or authentic scientific practice. A clear connection between the how students use the technology to interpret the science with peers motivates them to make clear connections with content.

Interaction and Immersion

Scientists use technology to reproduce influential factors of scientific events. To better understand these events, scientists have an opportunity to immerse themselves in virtual scenarios that replicate real-world occurrence. Educators have historically used models, and more recently games, to engage students in learning about real science principles. Here, games are defined as activities that in some sense include rivalries, strategies, or procedures toward a particular end. Games have increasingly become a contested and an acceptable method of learning science as well as cultivating science skills and dispositions (Shaffer et al. 2005). Games not only allow students to engage in dynamic play to develop and project identities (Gee 2003), but also afford immersion into ideological worlds and contested spaces (Squire 2006). The assertion is that these learning opportunities compel students to make critical decisions as they continue on an indeterminate journey. The following examples illustrate ways in which students oscillate between game player role and scientist role in order to participate with others. As they do so, students gain a deeper understanding of scientific concepts and processes.

Simulations are one form of immersion that enhances students' development of scientific knowledge (Meier et al. 2008). Participatory simulations are a set of role-playing activities designed to give students insight into the evolution of complex dynamic systems. The intention of these learning designs is to have students take on different roles while making decisions or "being part" of unfolding phenomena. The expectation is that students will then gain a better command of the underlying scientific concepts. Further, students will gain a sense of the influence of their role on the system. For example, students become doctors, medical technicians, and public health experts to understand infectious diseases (Rosenbaum et al. 2007). The submersion in actively taking on and understanding multiple roles and their influence, students begin to use scientific language (contagious, exposure, symptoms, infections, incubation period, epidemiologists, epidemic, quarantining, and immunity) as part of their conversations in the learning environment (Neulight et al. 2007). Students articulate that their partaking in participatory simulations provides an authentic experience. Namely, students become part of the system as they attempt to avoid getting the disease. If students get the disease, the immediate community aims toward the goal of interacting with other roles to find out how to make each other better. Attaining these self-developed learning goals and insights required and motivated students to understand the scientific principles involved. Moreover, students share that they enjoyed the dynamics of the simulation and felt they realized how their actions affected the unfolding nature of the system (Rosenbaum et al. 2007). The social and technical aspects of the design revealed particular affordances for learning. However, researchers found that students' misconceptions revealed themselves (Rosenbaum et al. 2007) and their biological explanations were still incomplete (Neulight et al. 2007). It is plausible then that teachers and designs must help students to make more explicit connections between activity and understanding as noted in similar research studies (Abelson 2008). Tools such as online chats or notebooks could be one means by which teachers can follow students' progress, assumptions, and developing ideas. These in turn can support teachers efforts to identify misconceptions early enough to help transform the learning tasks and cultivate more scientific explanations.

Multi-user Virtual Environments (MUVEs) are an increasingly desirable space in which students participate in their leisure time. These 3D spaces are seen to be valuable ways to immerse students in the teaching and learning of science. Students can interact with digital artifacts and other members of the learning environments through controlling avatars, which are personal virtual representations. Their avatars interact with each other and with programmed characters in the environments that are designed to act as cognitive scaffolds and assist with navigating problem sets. MUVEs, like Quest Altantis, require that students create rich narratives within their experiences. These help place the user in the role of antagonist, where students are acting out game-specific challenges (Barab et al. 2007). Narratives developed in conjunction with these games help students practice and develop scientific skills (Squire and Jan 2007). These designed experiences put students in "worlds" that encourage them use tools resources and tools within the environment to continue reading texts, generating meaning, debating meanings, and formulating new ideas (Squire and Jan 2007). In these worlds students develop ideologies about their world and the implications of decisions that they make. The situated (Greeno et al. 1995) nature of learning helps students make ties between goals of activity and place. Not all the participation takes place within the virtual space. Students report that they are "physically interacting with the simulated environment" (Rosenbaum et al. 2007, p. 38) but that they also interact and access resources offline to "win" the game. Affordances of the combination of virtual game and physical space structures are the creation of a hybrid or third space. These spaces are "neither completely fantastic nor completely real" (Squire and Jan 2007, p. 24) but work in concert with offline activity to provide students with a sensory experience that contributes to an authentic learning environment.

Conclusion and Implications

Throughout history technology has been an integral aspect of scientific work. For scientists, technologies have had a particular purpose and are more often than not a transparent part of their daily activities. It is noticeable that over the years, educators and designers are attempting to emulate this use of technology in the teaching and learning of science. Great strides have been taken to balance learning and technology as opposed to considering technology as a layer on top of or a resource that is superfluous to learning. This evolution affords opportunities for learners to be a more active part of learning science. New learning designs that see technology as integral to learning have illustrated the importance of giving equal attention to the social and technology elements of learning. Moreover, both the social and technical are integral to assisting students in their development of scientific literacy and twenty-first-century skills.

Throughout the advanced understanding about the nature of learning, variations of integrating technology have repeatedly highlighted how technology and social practices are essential to learning. This realization brings about particular design implications as designers of both technologies and learning seek to move forward. The implementation of technology in learning science suggests teaching and learning models that place students in the center of learning. For example, models that reflect cognitive apprenticeship are a way to illustrate scientific examples and processes for students. The technology works in various ways to do this.

Technology can act as a support to providing examples, dialogue, inquiry, and visualizations. IT can afford students the opportunity to see models and interact with them. They can engage students in interesting virtual worlds with interactive and attention-grabbing elements. Technology certainly has its power for motivation and engagement. However, it is only as good as the overarching learning design that taps the equally powerful learning aspects of human interaction. In other words, technology used to support teaching and learning is only as good as the sound educational practices that accompany them. Furthermore, "Technology is most effective when it meets a need and fits naturally into the overall educational context. Absent these conditions, it can be a distraction" (Miller and Upton 2007, p. 136).

The examples in this chapter represent various designs and the findings of their implementation. While the findings are not identical, they all point to a resounding theme. That is that without a balance of offline activities, the technology alone cannot support scientific literacy and twenty-first-century skills. Specifically, technical tools that support inquiry or offer simulations, for example, are not successful without group work (Lipson 2006). In groups, students draw on social resources and teacher guidance to make explicit connections between technology use and scientific content (Mayer 2004). Teachers need to help students through the use of cognitive organizers or other scaffolds to ensure that students access and select relevant material, organize it into meaningful representations so it will integrate into their exist knowledge (Mayer 2001). The technology is clearly a vehicle that assists learning, but it is the interconnected relationship between social and technical that brings about the most effective learning designs for science education.

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Chapter 86
The Impact of Student Clustering on the Results of Statistical Tests

Jeffrey P. Dorman

Introduction

The unit of analysis problem has been an ongoing issue in classroom-based research. In particular, how to analyse quantitative data collected from students is of particular concern because classroom researchers often rely on the collection of perceptual data from students nested in classes within schools. The data are clearly hierarchical and multi-level analysis textbooks consistently use school settings as exemplars of data hierarchy (e.g. Goldstein 2004; Hox 2002). Indeed, Harvey Goldstein (2003a) asserted that education was the first social science to fully develop multi-level modelling. While much literature on data analysis involving nested or clustered data has focused on choosing the right unit of analysis, Lee Cronbach (1976), Leigh Burstein (1980) and Stephen Raudenbush and Douglas Willms (1991) noted that the key issue is not one of choosing one unit of analysis, but the recognition of variation in scores at different levels. As science educators often conduct research with students in laboratories and classrooms, how to analyse quantitative data appropriately is clearly of great importance to research findings and subsequent conclusions.

The purposes of this chapter are threefold. First, it explores the effect of clustering on the results of statistical testing. An index of the degree of clustering of individuals at one level within another level (e.g. students within classes) is the intra-class correlation (or variance partition coefficient). Thus, I investigate how the intra-class correlation influences the results of statistical testing. As demonstrated below, this effect is primarily through the inflation of Type I error rates. Second, the chapter demonstrates a simple approach that corrects statistical inference parameters for inflated Type I error rates due to clustering. Third, the chapter applies the above

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theory to science laboratory classroom environment research with a data set from an Australian study. Before addressing these purposes, this chapter provides background information on assumptions of tests of statistical significance and issues relating to the clustering of data.

Background

Assumptions of Tests of Statistical Inference

A review of any introductory text or course on inferential statistical methods indicates that there are three basic assumptions in the conduct of independent *t* tests and analysis of variance (ANOVA): samples are randomly drawn from normally distributed populations with unknown population means (i.e. the normality assumption); population variances of the groups are equal (i.e. the equal variance assumption); and the scores of each respondent are not related to the scores of other respondents (i.e. the independence of observations assumption (see, e.g., Kanji 2006; Stevens 1999).

Researchers might not be fully aware of the robustness of statistical tests to violations of these assumptions prior to conducting statistical tests. This robustness concerns the extent to which the Type I error rate (the probability of rejecting the null hypothesis when it is, in fact, true) is inflated because of one or more of these assumptions being violated. According to James Stevens (1999), violation of the normality assumption does not significantly affect the Type I error rate in *t* tests and ANOVAs. Gene Glass, Percy Peckham and James Sanders provide great historical detail on this issue and demonstrate the minimal effect that high kurtosis and skewness have on *t* test and ANOVA results (Glass et al. 1972).

The second assumption, equality of variances, has been shown not to significantly influence Type I error rates unless there is a disparity in group sample sizes. Stevens (1999) suggests that provided that the largest/smallest group sample size ratio is less than 1.5, group population variances can be taken as equal. That is, *t* tests and ANOVAs are robust to unequal variances.

The third assumption, independence of observation, is the most important and, as Stevens (1999) asserts, even a small violation of this assumption produces a substantial effect on the actual Type I error rate and power of *t* tests and ANOVAs. Glass et al. (1972) noted the serious effect that non-independence of observations has on the level of significance of *F* tests. Non-independence of observations will be apparent when non-zero intra-class correlations among means of repeated samples are recorded. William Cochran (1947) and Henry Scheffé (1959) demonstrated the effect of these intra-class correlations on the actual Type I error rates. Positive correlations result in a liberal test (i.e. inflated Type I error rate) and negative correlations producing a more conservative test (deflated Type I error rate). John Walsh (1947) studied the influence of intra-class correlations on confidence intervals and significance levels of the Student *t*, χ^2 and *F* distributions. Subsequently, Robert Barcikowski (1981) used Walsh's formulae to compute Type I error rates for different intra-class correlations. Raja Velu and Maurice McInerney (1985) provided a method for adjusting F values if the assumption of independence is violated. Collectively, these articles highlight the impact on statistical tests results if the independence of observation assumption is violated.

The focus of this chapter is this third assumption and the fact that much research in educational settings is conducted with clustered samples in which data hierarchy is evident. It cannot be assumed that respondents who are clustered are statistically independent. For example, it is very unlikely that students in a science laboratory are statistically independent, especially with regard to the collection of data related to laboratory experiences. As the possibility of violating this third assumption is very real, statistical tests have to be modified or different approaches that recognise data clustering have to be employed.

Collecting Data from Intact Classes: Cluster Sampling

Much classroom research involves the collection of data from students who are clustered in classes. Such cluster sampling is one routine sampling approach discussed in most introductory educational research methods texts. For example, Lawrence Neuman (2006) describes the identification of a sample of clusters, each of which contains elements, and then draws a second sample from these clusters. While introductory texts usually discuss the advantages and limitations of cluster sampling, issues concerning the analysis of clustered data are often overlooked. Of particular concern are designs which have few clusters, with each cluster having a large number of members who are largely homogeneous with respect to the attributes being investigated. It is administratively efficient for classroom researchers to survey fewer classes and to collect data from all students in these classes. However, as Earl Babbie (2004) notes, the general cluster sampling principle is the reverse: increase the number of classes in the sample and decrease the number of students surveyed in each class.

While the hierarchical/nested nature of clustered data is clear, this essential characteristic has often been ignored when analysing data. Analyses have used either the individual as the unit of analysis and ignored class membership or the class as the unit of analysis with aggregated data and thus ignored the individual student. In response to criticisms, some researchers have reported parallel but essentially independent sets of analyses conducted with both the individual student and the class as units of analysis in the one study (e.g. Goh and Fraser 1998).

Proponents of multi-level modelling have argued that the existence of grouping hierarchies in data is neither accidental nor ignorable (see Rowe, 2007) and that data with a clear hierarchy should not be analysed as if they are all on the same level because this can lead to statistical and interpretational errors (Tabachnick and Fidell 2007). David Murray, Peter Hannan and William Baker noted that investigators who employ an analysis at the level of the individual run a very real risk of overstating the statistical significance reported for the test (Murray et al. 1996).

The fundamental issue concerning group effects is that, even if individuals are assigned to groups on a random basis, as a group, they will become differentiated. Students influence, and are influenced by, other students in the class (Goldstein 2003b). There is a class effect. It is also true that schools can create class effects by directing students to classes on biased bases (e.g. timetabling constraints, specialist teacher availability, subject choice, specialist classroom and laboratory availability). In essence, variance in students' scores can be partitioned at the student, class and school levels. The intra-class correlation, ρ or variance partition coefficient (VPC) is the proportion of variance accounted for by higher-level units and can be thought of as the 'extent of clustering' (Goldstein et al. 2002). Qualitatively, the VPC can be taken as a measure of the importance of the particular level. So the computed value for the VPC for classes provides an indication of how important class membership is to scores on the particular variable under consideration. According to Tom Snijders and Roel Bosker (1999), intra-class correlations for most educational settings range typically from 0.05 to 0.20. However, parameter values are dependent on the setting and variables under investigation. Valerie Lee (2000) asserted that a variance proportion above 10% at any level is non-trivial and needs to be taken into account in any analysis. However, Kyle Roberts (2007) was particularly critical of intra-class correlation thresholds as precursors to multi-level analysis. He cautioned that, even with intra-class correlations near zero, group dependence can exist when variables are added to the model.

Aggregating data to the class level usually involves computation of class means for each scale and analyses based on these mean scores. In essence, student-level variation is ignored and variance is compressed. Information is lost from the analysis; statistical power is lost (Hox 2002). Additionally, aggregation of data to higher levels raises the issue of aggregation bias and ecological fallacies in which a relationship identified statistically at a higher level is used to make assertions about lower-level variables (e.g. Alker, 1969; Freedman 1999). According to Murray Aitkin and Nicholas Longford, employing aggregated data 'is dangerous at best and disastrous at worst' (Aitkin and Longford, 1986, p. 42).

From a statistical perspective, if data are to be analysed using the student as the unit of analysis, an effective sample size which takes into account the *design effect* of having students nested in classes can be employed (Snijders and Bosker 1999). The higher the VPC, the higher is the design effect, and the greater the adjustment in the sample size if analysis is conducted at the individual level only. Another way of dealing with this issue is to conduct analyses with the student as the unit of analysis and the existing sample size, and then adjust post hoc the values of statistical parameters being used to make statistical inferences.

Multi-level modelling is the best approach to analysing hierarchical data with programmes like MLwiN (Rasbash et al. 2005) and HLM (Raudenbush and Bryk 2002) readily available. However, sometimes the raw data from a research report might not be available for re-analysis. In this case, multi-level analysis cannot be employed and a post hoc procedure based on the results of statistical testing and the sample characteristics is needed. The following section describes statistical theory of this latter approach according to Larry Hedges (2007). A later section of this chapter demonstrates this useful approach with a laboratory environment data set.

Adjusting Statistical Parameters for Clustering

Hedges (2007) provides an approach that addresses the three purposes of the present chapter. This theory focuses on two-group comparisons and the influence of the nesting of data. The intra-class correlation (ρ) is defined as

$$\rho = \frac{\sigma_B^2}{\sigma_B^2 + \sigma_W^2}$$

where σ_B^2 is the common between-cluster variance and σ_W^2 is the common within-cluster variance. It is the proportion of total variance attributed to between-cluster variation. As such, the intra-class correlation (or variance partition coefficient) is a measure of clustering. Higher values of ρ indicate higher clustering with $\rho = 1$ indicating no within-cluster variability. Similarly, if $\rho = 0$, there is no clustering effect and all cases can be treated as statistically independent.

If $\rho \neq 0$, then clustering should be taken into account in any statistical testing. While multi-level modelling would be the optimal approach, it is sometimes useful to proceed by adjusting existing parameters of statistical tests. The normal approach to comparing population means using samples from two groups is a *t* test. If clustering is ignored, the test is

$$t(N-2,\alpha)(\text{i.e.,} t \text{ score with } N-2 \text{ degrees of freedom})$$

According to Hedges (2007), the appropriate test if clustering is taken into account and cluster sizes are equal is

$$t_A = ct$$

where the adjusted *t* value, t_A, has a *t* distribution with *h* degrees of freedom, with

$$c = \sqrt{\frac{(N-2)-2(n-1)\rho}{(N-2)(1+(n-1)\rho)}}$$

and

$$h = \frac{\left[(N-2)-2(n-1)\rho\right]^2}{(N-2)\ (1-\rho)^2 + n(N-2n)\ \rho^2 + 2(N-2n)\rho(1-\rho)}$$

where
N = total sample size
n = number of students in each cluster/class
t_A is the adjusted *t* score with *h* degrees of freedom
ρ in the intra-class correlation

Table 86.1 Actual significance levels for different numbers of students per class in a two-group comparison for three nominal t test significance levels (15 classes per group, $\rho = 0.20$)

	Actual t test significance levels		
Students per class	$\alpha = 0.05$	$\alpha = 0.01$	$\alpha = 0.001$
5	0.145	0.055	0.014
10	0.243	0.125	0.050
15	0.317	0.188	0.092
20	0.374	0.242	0.135
25	0.419	0.288	0.173
30	0.455	0.326	0.209

Apart from the nominal significance level, three variables, N, n and ρ appear to influence the adjusted t value. To illustrate these effects within a school context, a series of computations was performed with students nested in classes. The number of classes per group was fixed at 15 per group and ρ was set at 0.20. Table 86.1 shows the effect of varying the number of students in each class in this two-group comparison. As shown in Table 86.1, the adjusted t test significance level has inflated dramatically. A two-group comparison with 15 classes per group and 30 students per class ($N = 900$) has an actual significance level of 0.455 – over nine times the nominal α of 0.05. The effect is even more pronounced when the nominal α is 0.001 with the inflationary effect being over 200 times. Similar analyses were conducted in which the number of classes per group and the number of students per class was fixed. These analyses indicated that the actual type I error rate was largely invariant to the number of classes per group.

To illustrate the effect of the intra-class correlation ρ on actual significance levels, three graphs for nominal α of 0.05, 0.01 and 0.001 have been drawn for the two-group comparison of 15 students per class and 20 classes in each group ($N = 600$) (see Fig. 86.1). The effect is pronounced with Fig. 86.1 showing that even a relatively small increase in the value of the intra-class correlation can create sizeable changes in the actual Type I error rate. For example, with nominal α set at.0.05, an intra-class correlation of 0.10 yields an actual significance level of 0.210. One noteworthy feature of these graphs is their linearity with Pearson correlation coefficients of 0.978 for $\alpha = 0.05$, 0.994 for $\alpha = 0.01$ and 0.992 for $\alpha = 0.001$. These graphs illustrate the importance of nesting to statistical test results.

If t values are known for analyses conducted with the individual student as the unit of analysis, the simple formula

$$t_{\mathrm{A}} = ct$$

where t_{A} has h degrees of freedom can be used to adjust for the nesting of data. The adjusted t score with h degrees of freedom can then be compared with the nominal value for α to ascertain whether statistical significance remains. If $\rho > 0$, then $0 < c < 1$ and so $t_{\mathrm{A}} < t$ for any nominal α and any ρ. Whether or not the computed value

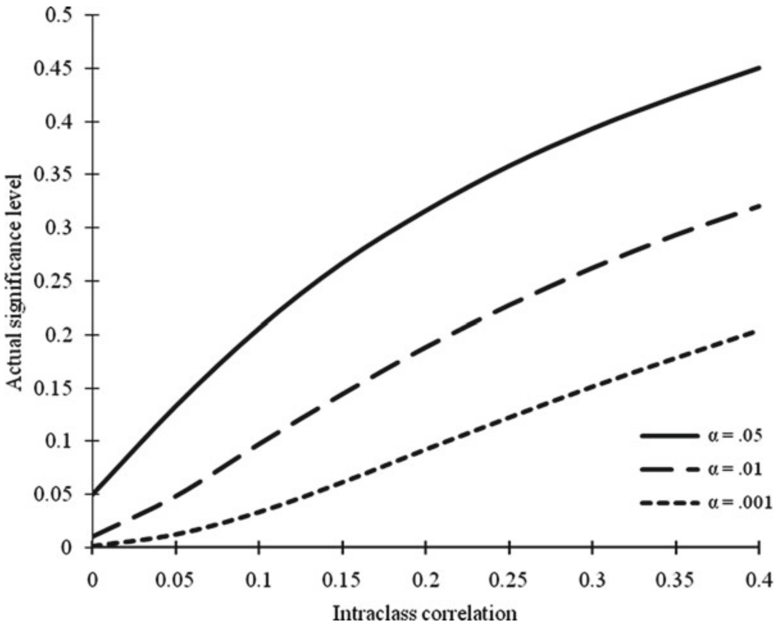

Fig. 86.1 Actual significance levels for different intraclass correlations for a two-group comparison (15 students in each class, 20 classes in each group and nominal $\alpha = 0.05$, 0.01 and 0.001)

of t_A falls in the critical region of the t_A distribution depends on the extent to which c adjusts t downwards and h. Furthermore, if t_A still falls within the critical region, the value of ρ needed for t_A to move outside the critical region can be computed using the critical values of the t distribution and the formula for c above.

Adjusting Statistical Parameters for Clustering in Science Laboratory Classroom Environment Research

To illustrate the theory described above, a data set from a laboratory classroom environment study conducted in Australian high school laboratories has been analysed. In this study, a sample of 1,522 students from 84 classes (42 Grade 9 and 42 Grade 12 classes) in 16 secondary schools responded to the Science Laboratory Environment Inventory (SLEI, Fraser 2007). To investigate difference in classroom environment in Grade 9 and 12 classes, a series of t tests with the student as the unit of analysis was conducted with clustering of students in the 84 classes ignored. Additionally, the above theory was used to compute inflated actual Type I error rates if clustering is ignored. Adjusted t test results that take into account the clustering of students in classes are also presented.

Table 86.2 Descriptive Information for SLEI scales

SLEI scale	Scale description	Coefficient α				Analysis of variance for class membership	
		Student	Class	*M*	*SD*	*F* (83, 1439)	η^2 (%)
Student cohesiveness	The extent to which students know, help and are supportive of one another	0.79	0.85	3.02	0.55	3.04*	14.91
Open-endedness	The extent to which the laboratory activities emphasise an open-ended, divergent approach to experimentation	0.69	0.80	2.52	0.64	4.42*	20.20
Integration	The extent to which laboratory activities are integrated with non-laboratory and theory classes	0.84	0.88	3.07	0.64	2.73*	13.59
Rule clarity	The extent to which behaviour in the laboratory is guided by formal rules	0.72	0.84	2.61	0.73	2.96*	14.52
Material environment	The extent to which laboratory equipment and materials are adequate	0.75	0.86	3.07	0.69	3.51*	16.77

Note: Means and standard deviations are based on per item scale scores with the individual student as the unit of analysis
*$p < 0.001$

The SLEI consists of 35 items assigned to five underlying scales (Student Cohesiveness, Open-endedness, Integration, Rule Clarity and Material Environment). Each item employs a five-point Likert response format (viz. strongly disagree = 1, disagree = 2, neither = 3, agree = 4, strongly agree = 5) with item scores aggregated to form scale scores for each respondent. Table 86.2 shows descriptions for each SLEI scale. Further descriptive information and validation data for the SLEI are provided by Barry Fraser et al. (1995). As shown in Table 86.2, reliability coefficients (Cronbach coefficient α) ranged from 0.69 for Open-endedness to 0.84 for Integration with the individual as the unit of analysis, and from 0.80 to 0.88 for the same scales with the class as the unit of analysis. Table 86.2 also shows results of analysis of variance tests conducted for class membership effects for each scale. The proportion of variance explained by class membership ranged from 13.59% for Integration to 20.20% for Open-endedness. Means and standard deviations are also listed in Table 86.2.

Use of Student as Unit of Analysis in t Tests with Clustering Ignored

Seven *t* tests with the student as the unit of analysis were used to compare classroom environment according to grade level (i.e. Grade 9 and 12 classes). Class membership (i.e. class clustering) was ignored. That is, these analyses assumed that all students were statistically independent. As the present analysis involved seven independent tests, the use of the Bonferroni inequality resulted in the nominal Type 1 error rate of 0.05 being adjusted downwards to the more stringent benchmark of 0.01 for all tests. Statistically significant differences in scale scores for Grades 9 and 12 students were found for all five SLEI scales: Student cohesiveness [t (1,520) = 5.40, p <.001], Open-endedness [t (1,520) = –2.95, p < 0.001], Integration [t (1,520) = 3.10, p < 0.001], Rule clarity [t (1,520) = –4.63, p < 0.001] and Material Environment [t (1,520) = −2.58, p < 0.001], with respective effect sizes using Jacob Cohen's (1998) *d* of 0.28, 0.14, 0.16, 0.25 and 0.14. Compared with Grade 9 laboratory classes, Grade 12 laboratory classes had lower Student Cohesiveness and Integration but higher Open-endedness, Rule clarity and Material Environment.

However, as indicated by the theory presented earlier in this chapter, actual Type 1 error rates can be inflated substantially if there are appreciable intra-class correlations (ρ) (i.e. the proportion of variance explained by class membership). Multi-level analysis with MLwiN (Rasbash et al. 2005) with the student as the first-level variable and class as the second-level variable was used to compute intra-class correlations for Student Cohesiveness (0.101), Open-endedness (0.156), Integration (0.096), Rule Clarity (0.094) and Material Environment (0.119).

For these three comparisons, the actual Type 1 error rates computed with the above theory were 0.119, 0.179, 0.113, 0.111 and 0.140, respectively – up to 17 times the nominal level of 0.01. If a nominal level of 0.05 had been adopted, then the respective actual Type 1 error rates would be 0.236, 0.307, 0.228, 0.225 and 0.261. These are unacceptably high Type I error rates. That is, the probability of concluding that differences exist between Grade 9 and 12 laboratory classroom environments, when in fact there are not differences, is much too high. Accordingly, the potential for invalid results and conclusions if clustering is ignored is very real.

Adjusting t Scores for Clustering

The above *t* scores can be adjusted to take clustering into account by using the formula

$$t_{\mathrm{A}} = ct$$

where t_{A} is the adjusted *t* score with *h* degrees of freedom, *c* is defined earlier in this chapter in terms of class size, number of classes and the intra-class correlation, and *t* is the *t* score with clustering ignored. The mean class size of 18.12 was employed in all of these analyses. Using the theory described above, adjusted t scores (t_A) and Type 1 error rates were computed: Student cohesiveness [t_A (1,297) = 3.27, $p = 0.001$], Open-endedness [t_A (1,077) = 1.53, $p = 0.125$], Integration [t_A (1,316) = 1.90, $p = 0.057$], Rule clarity [t_A (1,323) = 2.87, $p = 0.004$] and Material Environment [t_A (1,227) = 1.48, $p = 0.140$]. These new t values shed light on these comparisons, with only Student Cohesiveness and Rule Clarity now showing statistically significant differences between Grade 9 and 12 laboratory classroom environments with a nominal Type 1 error rate of 0.01.

It is also possible to compute the intra-class correlation that would need to be exceeded for the adjusted t score for Task Orientation to exceed the critical value with $p = 0.01$. In the present study, this value was computed to be 0.197 for Student Cohesiveness and 0.130 for Rule Clarity. Analogously, how low the intra-class correlation would need to be for Open-endedness, Integration and Material Environment t scores to be above the critical value can be calculated. With $p = 0.01$, the intra-class correlations for Open-endedness, Integration and Material Environment would need to be below 0.018, 0.026, and 0.001, respectively – well below the observed the values of 0.156, 0.96 and 0.119, respectively.

Further Analyses: t Tests with the Class as the Unit of Analysis and Multi-level Analyses

To further study the unit-of-analysis issue with these data, the above set of analyses with the individual as the unit of analysis was complemented by two further sets of analyses. In the second set, t tests for the effect of grade level on science laboratory classroom environment with the class as the unit of analysis and the class mean as the measuring statistic were performed. A third set of analyses employed multi-level analysis using MLwiN (Rasbash et al. 2005).

Five t tests with the class as unit of analysis revealed statistically significant differences between Grade 9 and 12 students for two scales: Student Cohesiveness [t (82) = 2.86, $p < 0.01$] and Rule Clarity [t (82) = -2.79, $p < 0.01$]. Effect size magnitudes were 0.67 for both comparisons. The directions of these differences were the same as analyses with the student as the unit of analysis: Grade 12 students reported lower Student Cohesiveness but higher Rule Clarity than Grade 9 students. However, because of variance compression in using the class mean as the measuring statistic, effect sizes were inflated compared to those reported with the student as the unit of analysis.

Multi-level analyses involved base variance components (i.e. null) models created for each science laboratory classroom environment scale and conditional models in which grade level was entered as the predictor or explanatory variable in regression equations. Base variance components models can be compared with traditional ANOVAs for class membership which are reported in Table 86.2. Two improvements to the treatment of scores as advocated by Ken Rowe (2007) were performed before these multi-level analyses. First, factor score regressions derived from

Table 86.3 Variance components multi-level models for SLEI scales

	Multi-level Modelling (Residual Variance)			
	Between students		Between classes	
SLEI scale	σ^2	%	σ^2	%
Student cohesiveness	0.267 (0.010)*	89.90	0.030 (0.007)*	10.10
Open-endedness	0.342 (0.013)*	84.44	0.063 (0.013)*	15.56
Integration	0.369 (0.014)*	90.44	0.039 (0.009)*	9.56
Rule clarity	0.481 (0.018)*	90.58	0.050 (0.012)*	9.42
Material environment	0.422 (0.016)*	88.10	0.057 (0.013)*	11.90

*p <.001

confirmatory factor analyses were used to weight items when computing scale scores. This approach minimises measurement error variance for each scale (see Holmes-Smith and Rowe 1994). Second, scores for all five scales employed in this study were normalised prior to regression analyses. This approach attenuated the effect of non-normal univariate and multivariate scale score distributions, especially with regard to departures from normality in scale kurtosis. These normal scores were employed in the multi-level analyses reported below.

Separate multi-level models for each science laboratory classroom environment scale were created. Grade level was coded as Grade 9 = 1 and Grade 12 = 2. For multi-level analyses, correlations between explanatory and response variables were used to compute equivalent effect sizes using Cohen's formula $r^2 = d^2/(4+d^2)$. This procedure provided a common metric for comparing effect sizes across the analyses.

Results of the ANOVAs for class memberships are shown in Tables 86.2. The η^2 statistic, which is the proportion of variance explained by class membership, ranged from 13.59% for integration to 20.20% for open-endedness. The important observation from the results of the variance components models shown in Table 86.3 is that, for all scales, all between-student and between-class variances were statistically significant ($p < 0.001$). As expected, most of the variance in scales scores was at the student level, with the proportion of variance at this level ranging from 84.44% (Open-endedness) to 90.58% (Rule Clarity). The highest intra-class correlation was for Open-endedness (15.56%). There is substantial clustering at the class level for all scales. This supports the view that the nested nature of the data with regard to class membership should not be ignored in subsequent analyses.

To compare the results of the three sets of tests described above, Table 86.4 has been assembled. It shows that multi-level analyses for the effect of year level revealed statistically significant estimates similar to t tests with the class as the unit of analysis. Parameter estimates for Student Cohesiveness and Rule Clarity were statistically significant ($p < 0.01$). Effect size magnitudes were similar to those for the univariate analyses with the student as unit of analysis: 0.31 for Student Cohesiveness and 0.23 for Rule Clarity). In summary, the results of the multi-level analyses were consistent with those for t tests with the class as unit of analysis, but effect sizes were more aligned with comparisons with the student as the unit of analysis.

Table 86.4 Results of multivariate analyses of variance and multi-level analyses with effect sizes

Explanatory and response variables	*t* test with student as unit of analysis (*N* = 1,522 students)		*t* test with class as unit of analysis (*N* = 84 classes)		Multi-level analysis (1,522 students nested in 84 classes)	
	t (1,520)	Effect size	*t* (82)	Effect size	Estimates	Effect size
Student cohesiveness	5.40	0.28	2.86	0.67	0.158 (0.044)	0.31
Open-endedness	−2.95	0.14	–	–	–	–
Integration	3.10	0.16	–	–	–	–
Rule clarity	−4.63	0.25	−2.79	0.67	−0.170 (0.059)	0.23
Material environment	−2.58	0.14	–	–	–	–

Note: Only *t* values that are statistically significant at $p < 0.01$ are shown. For multi-level analyses, only estimates for statistically significant explanatory variables in each model with $p < 0.01$ are shown. Standard errors are shown in parentheses. Grade level was coded as Grade 9 = 1, Grade 12 = 2

Discussion

There are four important implications to be drawn from the theory and application presented in this chapter. First, this chapter has demonstrated that it is improper to analyse clustered data as if all respondents are statistically independent. This is because the intra-class correlation, inherent in clustered data, inflates the Type I error rate. Of interest is the magnitude by which the intra-class correlation inflates the nominal Type I error rate. This chapter has shown that even modest values of the intra-class correlation (i.e. $0.05 < \rho < 0.10$) have quite dramatic effects on Type 1 error rates. Figure 86.1 demonstrates that with nominal α set at 0.05, intra-class correlations of 0.05 and 0.10 yield actual significance levels of 0.133 and 0.206, respectively. With regard to classroom research, the potential for committing Type I errors is very real mainly because intra-class correlations are potentially much higher. Seminal research using the SLEI by McRobbie and Fraser (1993) in high school chemistry classes revealed η^2 coefficients (the proportion of variance explained by class membership in a one-way ANOVA) that range from 0.24 for Student Cohesiveness to 0.34 for Open-endedness. When used in a cross-national study of university science students, Fraser et al. (1995) reported η^2 coefficients for SLEI scales that ranged from 0.20 for Open-endedness to 0.34 for Rule Clarity. More recently, a modified version of the SLEI was used in a Singaporean study of chemistry classrooms with η^2 coefficients ranging from 0.06 for Open-endedness to 0.21 for Material Environment (Quek et al. 2005). Substantial adjustments to the nominal Type I error rate will be evident in all of these studies even if class sizes are relatively small.

Second, this chapter has demonstrated that, provided a good estimate of the intra-class correlation is available and basic sample parameters of cluster size and total sample size are known, it is possible to compute adjusted parameter values without access to the raw data. As illustrated with the application of the theory to a science laboratory classroom environment data set, there can be substantial changes in parameter estimates which can lead to a reversal of conclusions concerning statistical significance. That is, parameter estimates without intra-class correlation adjustments can indicate that the null hypothesis should be rejected and conclude that there are significant differences between the groups. In contrast, parameter estimates with intra-class correlation adjustments can indicate an acceptance of the null hypothesis. Thus one can easily commit a Type I error if clustering is ignored: falsely reject the null hypothesis and erroneously conclude that there are statistically significant differences between groups.

One limitation to these computations is that the intra-class correlation has to be estimated if it is not provided in the research report. While the η^2 statistic can be used, it also might not be provided in the research report. Hedges (2007) notes this problem and describes how various authors are establishing reference tables of intra-class correlations. For example, in the USA, Hedges and Hedberg (2007a, b) developed a compendium of several hundred intra-class correlations for academic achievement.

A third implication of these computations is that school and classroom researchers need to pay more attention to research design and in particular the selection of the sample. Historically, much classroom research has involved intact classes. This is efficient – it allows the collection of substantial numbers of completed questionnaires from one location in a short period of time. However, Table 86.1 shows the dramatic effect of cluster size on the Type I error rate. While the effect of the intra-class correlation on nominal Type I error cannot be attenuated, the effect of clustering can be reduced by reducing cluster size. Accordingly, classroom researchers should consider reducing the number of students per class surveyed and increasing proportionally the number of classes in the sample. For example, with a total sample set at 1,200, instead of surveying 40 classes with 30 students per class, it would be better to survey 120 classes and randomly select 10 students from each class to respond to the questionnaire. Analogously, school researchers wishing to reduce the effect of clustering at the school level should collect data from more schools but from fewer teachers or students per school.

The final issue concerns the comparison of multi-level analyses with multivariate tests conducted with the individual and the class as units of analysis. In the present illustration, the results of the multi-level analyses tests were very similar to the multivariate tests conducted with the class as the unit of analysis. However, effect sizes for the multivariate tests were inflated due to variance compression. One relevant issue in considering how to analyse data is whether the focus of investigation is the class or individual student. If it is the class, then the ecological fallacy issue is not a major issue, and therefore Aitkin and Longford's (1986) 'dangerous at best and disastrous at worst' warning for aggregated data would not apply. However, there is a clear need to discount the effect sizes when using the class as the unit of analysis.

Employing the student as the unit of analysis in multivariate analysis of variance is problematic. It should only be used when the variance partitioning coefficient (i.e. intra-class correlation) is very, very low or significant adjustments have been made to the effective sample size as advocated by Snijders and Bosker (1999).

Overall, this empirical illustration highlights the superiority of multi-level analysis over traditional multivariate analysis of variance in much classroom-based research. Statistical tests using multi-level analysis were consistent with multivariate tests with the class as the unit of analysis (and the class mean as the measuring statistic) and their effect sizes were more authentic than those computed with class mean data. Additionally, multi-level analysis also has the potential to be useful for studying cross-level interaction effects – that is, interactions between variables measured at different levels of the hierarchy (e.g. sex and grade level) (Kreft and de Leeuw 1998).

Conclusion

The purpose of this chapter was to elucidate the effect of clustering on the results of statistical testing and the potential problems that arise if nested data are treated as statistically independent. As much educational data are collected from students who are clustered in classes within schools, this issue cannot be ignored. Cluster size and intra-class correlation (or variance partition coefficient) were shown to have substantial effects on the inflation of Type I error probabilities. While multi-level analysis is the preferred approach to handling nested data, a relatively simple procedure for adjusting statistical parameter estimates for clustering was demonstrated.

The empirical illustration reported in the present chapter was a simple two-group comparison and employed *t* tests. Classroom researchers using traditional statistical methods (e.g. ANOVA) should not use the individual student as the unit of analysis unless techniques like those demonstrated in this chapter are employed.

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Part X
Literacy and Language

Chapter 87
Interdisciplinary Perspectives Linking Science and Literacy in Grades K–5: Implications for Policy and Practice

Nancy R. Romance and Michael R. Vitale

Recent appraisals of interdisciplinary research related to meaningful learning summarised in the report by the National Academy Press, *How People Learn* (Bransford et al. 2000), provide a foundation for why and how science as a form of in-depth, content-area instruction can serve as a core element in literacy development (e.g. reading comprehension, writing) in elementary schools. In their overview, Bransford et al. summarised consensus research into expert behaviour and expertise as a unifying concept for meaningful learning. Such studies have established that, in comparison to novices, experts demonstrate a highly developed organisation of knowledge that emphasises an in-depth understanding of the core concepts and concept relationships in their discipline (i.e. domain-specific knowledge) that, in turn, they are able to access efficiently and apply with automaticity. Although the instructional implications of such perspectives (discussed below) are highly supportive of the importance of in-depth, content-area learning, these same implications are in direct conflict with the present lack of emphasis on meaningful curricular content in popular approaches to reading and language arts that presently dominate elementary schools (e.g. Hirsch 1996, 2006; Walsh 2003) and have resulted in a de-emphasis on science instruction (Dillon 2006; Jones et al. 1999). In the following sections, a combination of theoretical perspectives and empirical findings is presented as a foundation for establishing the relevance of elementary science instruction implemented as a form of in-depth, content-area learning to the development of student proficiency in reading comprehension and writing. In doing so, this evidence-based argument provides a rationale for in-depth science instruction within which reading comprehension and writing are integrated

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as a major curricular strategy that has the potential for providing a curricular solution to systemic problems presently associated with school reform (Gonzales et al. 2008; Lee et al. 2007; Lutkus et al. 2006).

Interdisciplinary Research Underlying Meaningful Learning: Knowledge-Based Instruction Models

Interdisciplinary foundations of meaningful school learning draw from the complementary areas of cognitive science, cognitive psychology, applied learning, instructional design/development and educational research. Although there is a wide variety of such work, several key research-based perspectives represent primary tenets. The first has to do with the architecture of knowledge-based instruction systems (Luger 2008) originally developed for implementing computer-based intelligent tutoring systems. The second (Kintsch 1994, 1998, 2004) involves the importance of having a well-structured curricular environment for learning (Schmidt et al. 1997, 1999). The third (Bransford et al. 2000) is the role of knowledge as applied in the problem-solving behaviour of experts (i.e. expertise) relative to that of novices. The fourth has to do with cognitive research dealing with the linkage of declarative knowledge to procedural knowledge and automaticity (Anderson 1982, 1987, 1992, 1993, 1996).

Cognitive Science Foundations of Knowledge-Based Instruction Models

Implemented originally in computer-based intelligent tutoring systems (ITS), the distinguishing characteristic of knowledge-based instruction is that all aspects of instruction (e.g. teaching strategies, student activities, assessment) are related explicitly to an overall design that represents the logical structure of the concepts in the subject-matter discipline to be taught, a curricular structure that, while grade-appropriate, should parallel the knowledge organisation of disciplinary experts. In considering this design characteristic as a key focus for meaningful learning, knowledge-based instruction is best illustrated by the original ITS architecture developed in the early 1980s (e.g. Kearsley 1987; Luger 2008). As Figure 87.1 shows, in ITS systems, the explicit representation of the knowledge to be learned serves as an organisational framework for all elements of instruction, including the determination of learning sequences, the selection of teaching methods, the specific activities required of learners, and the evaluative assessment of student learning success. In considering the implications of knowledge-based instruction for education, it is important to recognise that one of the strongest areas of cognitive science methodology focuses on explicitly representing and accessing knowledge (e.g. Luger 2008; Kolodner 1993, 1997; Sowa 2000).

The research foundations of knowledge-based instruction models are consistent with well-established findings from cognitive science. In particular, Bransford et al.

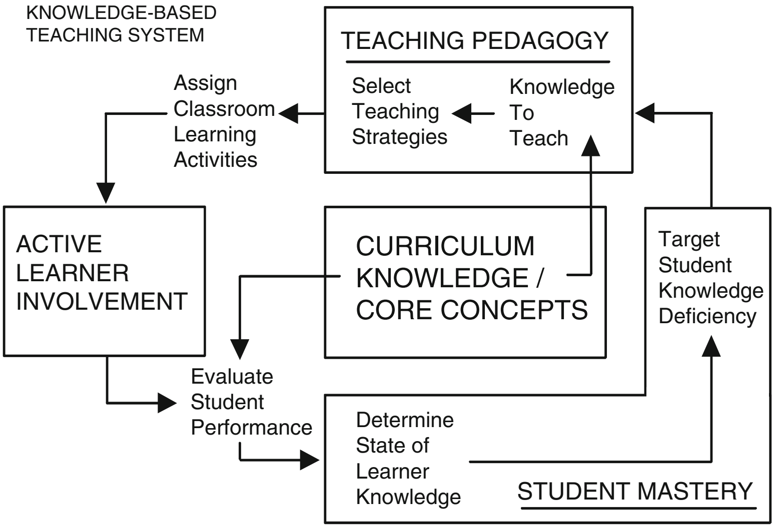

Fig. 87.1 Architecture for a knowledge-based intelligent tutoring system

(2000) stressed the principle that explicitly focusing on the core concepts and relationships that reflect the logical structure of the discipline and enhancing the development of prior knowledge are of paramount importance for meaningful learning to occur (see also Schmidt et al. 2001). Closely related to this view is work by Anderson and others (e.g. Anderson 1992, 1993, 1996; Anderson and Fincham 1994; Anderson and Lebiere 1998) who distinguished the ‘strong’ problem-solving process of experts as highly knowledge-based and automatic from the ‘weak’ strategies that novices with minimal knowledge are forced to adopt in a heuristically oriented, trial-and-error fashion. Also directly related are key elements in earlier versions of Anderson’s (1996) ‘ACT’ cognitive theory that (a) consider cognitive skills as forms of proficiency that are knowledge-based, (b) distinguish between declarative and procedural knowledge (i.e. knowing about vs. applying knowledge) and (c) identify the conditions in learning environments that determine the transformation of declarative knowledge to procedural knowledge.

In considering the role of prior knowledge in learning, the consensus research findings presented by Bransford et al. (2000) emphasised that both the conceptual understanding and use of knowledge by experts in application tasks (e.g. analysing and solving problems) are primarily a matter of accessing and applying prior knowledge (Kolodner 1993, 1997; Rivet and Krajcik 2008) under conditions of automaticity. As characteristics of learning processes, the preceding emphasises that extensive amounts of varied experiences (i.e. practice) focusing on knowledge in the form of the concept relationships to be learned are critical to the development of the different aspects of automaticity associated with expert mastery in any discipline. In related research, Murray Sidman (1994) and others (e.g. Artzen and Holth 1997; Dougher and Markham 1994) have explored the conditions under which extensive practice to automaticity focusing on one subset of relationships can result in additional subsets of relationships being learned without explicit instruction. In these studies, the additional relationships were not taught but, rather, were implied by the original set of relationships that were taught (i.e. formed equivalence relationships). In related work, both Mark Niedelman (1992) and Anderson and others (e.g. Anderson 1996) have offered interpretations of research issues relating to transfer of learning that are consistent with the knowledge-based approach to learning and understanding. Considered together, these findings represent an emerging knowledge-based emphasis on the linkage between the logical structure of what is to be taught with the instructional means for accomplishing meaningful learning.

A Knowledge-Based Framework for Approaching Comprehension Through Content-Area Instruction

The well-defined structure of the science knowledge (e.g. NSES Standards) appropriate for in-depth science instruction in K–5 schools fits well with knowledge-based, ITS-type instructional models. However, in order for such in-depth science instruction to be adopted as a primary means for developing student reading comprehension, schools must have an evidence-based rationale as a foundation for justifying increased time for science instruction. Because of the strong dependence of the role of prior knowledge in meaningful learning (Kintsch 1994, 1998, 2004), a knowledge-based approach to reading comprehension would consider reading comprehension as a subset of comprehension in general (Vitale and Romance 2007b). With this view in mind, all of the instructional strategies for engendering the development of science students' in-depth understanding (e.g. hands-on activities, inquiry-oriented questioning, journaling), therefore, are also applicable to building student proficiency in reading comprehension.

One approach to addressing the linkage of comprehension development to a knowledge-based approach to meaningful learning is the construction–integration model developed by Kintsch and his colleagues (e.g. Kintsch 1994, 1998, 2004). Kintsch's model explains the process of reading comprehension (and, by inference, comprehension) by distinguishing between the propositional structure (i.e. semantic meaning) of the conceptual content of a text that is being read and the prior knowledge that the reader brings to the process of reading. In this context, meaningful comprehension results when the prior knowledge of the learner can be joined with the propositional structure of the text. If the propositional structure of the text is highly cohesive (i.e. knowledge is explicitly well-organised in propositional form), then there is less demand upon readers' prior knowledge. But, if the text is not cohesive (i.e. contains significant semantic gaps), then the reader's prior knowledge is critical for understanding. In either case, comprehension consists of the integration of the propositional structure of the text with reader prior knowledge.

Within this framework, much of the research conducted by Kintsch and his colleagues (e.g. McNamara et al. 2007) has focused on the interplay of meaningful text structure and the prior knowledge of the reader considered as a learner. However, as noted above, the elements of the Kintsch model are readily generalisable to any form of meaningful learning in school settings that involves the interaction of students' prior knowledge with a (cohesive) curricular structure that, together, provide the context for meaningful learning. In this sense, Kintsch's model offers an evidence-based framework (e.g. McNamara and Kintsch 1996; Weaver and Kintsch 1995) that is supportive of the appropriateness of in-depth science instruction through knowledge-based models and of the linkage of such knowledge-based models focusing on science to the development of reading comprehension.

Combining the architecture of knowledge-based instruction with the construction–integration model of Kintsch (1994, 1998, 2004) allows a reinterpretation of research in reading comprehension in a manner that is directly relevant to the use of K–5 science curricula that are 'coherent' (see Schmidt et al. 2001) as a vehicle for building reading comprehension. Within the field of reading, both individual researchers (e.g. Block and Pressley 2002; Farstrup and Samuels 2002) and research groups (RAND Report, Catherine Snow 2002; National Reading Panel 2000) have investigated and evaluated different aspects of reading comprehension instruction. However, in evaluating such research, the RAND report concluded that present knowledge in the field is not yet adequate to systemically reform reading comprehension instruction, particularly the type of content-area reading comprehension that ultimately is required for success in textbook-oriented high school courses in science and other areas. In contrast, in recent interdisciplinary-oriented reading comprehension research, McNamara et al. (2007) concluded that skilled comprehenders are more able to use knowledge (and strategies) actively and efficiently to help them to comprehend text and, further, that individual differences in reading comprehension depend on the dynamics associated with such knowledge activation. Clearly, the activation of prior knowledge in combination with coherent curricular structure are key components of any instructional environment that focuses on the development of in-depth content-area understanding such as science or reading comprehension.

While education has addressed the role of knowledge in meaningful learning and comprehension (e.g. Carnine 1991; Glaser 1984; Hirsch 1996, 2001; Kintsch 1998), such attention was minimal until the publication of the Bransford et al. (2000) book (see Sean Cavanagh [2004] interview with David Klahr). However, consistent with McNamara et al.'s (2007) conclusions, Bransford et al. (2000) emphasised how conceptual frameworks as a form of prior knowledge facilitated new meaningful learning (i.e. comprehension in learning tasks). When these perspectives are considered together, it is the cognitive science perspective that provides the means to understand the dynamics of the important differences between what the reading comprehension literature has identified as proficient vs. struggling readers, particularly in instructional settings requiring content-area reading (see Catherine Snow 2002; Vitale and Romance, 2007).

One additional implication from Bransford et al. (2000) supported by others (e.g. Carnine 1991; Glaser 1984; Kintsch 1998; Vitale and Romance 2000) is that, from a knowledge-based perspective, curriculum mastery in schools should be approached as a form of expertise and that student conceptual mastery of academic content should be consistent with how experts perceive the discipline (see also Schmidt et al. 2001). In this regard, emphasising the in-depth understanding of core concepts and concept relationships in grade-appropriate form is a critical element of general comprehension and, by inference, of reading comprehension as well. In fact, a knowledge-based perspective of reading comprehension that is consistent with the broad idea of meaningful comprehension presented by Bransford et al. (2000) would suggest that the nature of comprehension in both general learning and reading-to-learn settings is equivalent (see Vitale and Romance 2007b), with the exception that the specific learning experiences associated with reading comprehension are text-based.

Support for Using Content-Area Instruction in Science as a Means of Enhancing Literacy Development at the Elementary Levels

Following from the preceding framework, the question of empirical support for and the relevance of linking in-depth science instruction to literacy development can be addressed. Because the disciplinary structure of science knowledge is highly cohesive, cumulative in-depth instruction in science provides a learning environment well-suited for the development of understanding as expertise. As a focus for meaningful learning in school settings, science conceptual knowledge is grounded on the everyday events that students experience on a continuing basis. In developing science knowledge, elementary students are able to (a) link together different events that they observe, (b) make predictions about the occurrence of events (or manipulate conditions to produce outcomes) and (c) make meaningful interpretations of events that occur, all of which are key elements of meaningful comprehension (Vitale and Romance 2006a). As discussed in the following sections, meaningful learning in science naturally incorporates critical elements associated with the development of curricular-based science expertise by students (e.g. acquisition and organisation of conceptual knowledge, experiencing a potentially wide range of application experiences that provide varied practice in learning). In turn, with the active development of such in-depth conceptual understanding in science serving as a foundation, the use of prior knowledge in the comprehension of new learning tasks, and in the communication of what knowledge has been learned, provides a basis for key aspects of literacy development.

Research Trends Recognising the Importance of Content-Area Instruction in Science in Primary (K–2) Grades

Because literacy development is a major focus in grades K–2, the lack of informational science materials to which young children are exposed in school settings is an important curricular policy issue. In this regard, David Pearson and Nell Duke (2002) noted that the terms 'comprehension instruction' and 'primary grades' seldom appear together and, along with others (e.g. Nell Duke et al. 2003; Pressley et al. 1996), reported that primary students experience minimal content-area instruction, despite an extensive research base that provides guidance on how and why such instruction should be pursued. Specifically, David Pearson and Nell Duke (2002) listed a series of research-based approaches involving teacher story reading (i.e. read-alouds) for building student content-area comprehension as early as kindergarten (e.g. asking meaningful questions about story elements, engaging students in retelling summarisations, using elaboration strategies such as theme identification, intensive text study through elaborative discussion). All of these approaches are highly knowledge-focused and inquiry-oriented and result in the development of domain-specific knowledge as long as such knowledge is available to be learned. As a result, such approaches fit well with an in-depth focus upon science and other content in instruction.

In addressing resistance to the use of informational text at the primary grades, David Pearson and Nell Duke (2002) also refuted major unsupported beliefs that serve as barriers (e.g. young children cannot handle them and are uninterested; comprehension is best at upper elementary grades). In a complementary analysis, Walsh (2003) noted that current basal reading series at the primary level are unable to engender meaningful knowledge development because they are designed specifically not to contain such knowledge. Walsh also noted that the problems subsequently evidenced by students in content-area text comprehension are due to lack of prior knowledge rather than deficiencies in reading skills or strategies.

In recent years, emerging K–2 curricular trends have emphasised an increased use of both informational texts in science and reading instruction and a more in-depth approach to science instruction in primary grades. In general, K–2 instructional interventions which emphasise the development of meaningful knowledge in science and other content areas are consistent with emerging literacy trends (Palmer and Stewart 2003) that emphasise the use of informational text for developing comprehension proficiency at the primary levels (see also Holliday 2004; Klentschy and Molina-De La Torre 2004; Ogle and Blachowicz 2002; Gould et al. 2003).

Other researchers have extended the notion of linking science with literacy in early childhood (preschool) programmes and have identified several benefits. For example, Lucia French (2004) has reported the feasibility of a curricular approach in which science experiences provide a rich learning context for an early childhood curriculum that results in early literacy development as well as science learning. Gelman and Brenneman (2004) have shown, from the standpoint of feasibility, how a preschool science programme which incorporates guided hands-on activities can be used as a framework for instruction that engenders the development of domain-specific knowledge in young children. Working with students aged 3–6 years, Carol Smith (2001) described how the active involvement of young children in gaining science knowledge is naturally motivating (see also Conezio and Lucia French 2002) if topics are approached with sufficient depth and time, a position consistent with the 1995 National Science Education Standards (NRC 1996). In representative work supporting different facets of science instruction at the primary level, Gould et al. (2003) informally described an approach for early science instruction with gifted students; Russel Tytler and Suzanne Peterson (2001) summarised the meaningful changes in 5-year-olds' explanations of evaporation as a result of extended in-depth science instruction; Jacqueline Jones and Rosalea Courtney (2002) addressed the processes of curricular planning for instruction and assessment in early science learning; Carol Armga et al. (2002) and Laura Colker (2002) suggested guidelines for teaching science in early childhood settings; and Michelle Lee et al. (2000) described the benefits of school-wide thematically oriented instruction in science.

In support of the preceding as an emerging trend, an article on a parallel theme by Robert Siegler (2000) discussed a rebirth of attention to children's learning within developmental psychology. Within this context, Herbert Ginsberg and Susan Golbeck (2004) offered thoughts on the future of research in science learning that encouraged researchers and practitioners to examine critically and to be open to the possibilities of unexpected competence in young children (e.g. Revelle et al. 2002), perspectives related to those of Lynn Newton (2001) and Hilary Asoko (2002) and highly consistent with the importance of in-depth science instruction at the primary level (see also Sandall 2003).

Research Trends Recognising the Importance of Instruction in Science for Literacy Development in Upper Elementary Grades 3–5

There are an expanding number of research initiatives at the upper elementary grades that have linked science instruction and literacy. Gina Cervetti and David Pearson (2006) reported results of a series of studies addressing the role of reading in learning science through their Roots and Seeds curriculum. Within their model, students first participate in inquiry-based, hands-on experiments to illustrate science concepts which are then followed by science reading assignments. Duke and her colleagues (Nell Duke 2000b, 2007; Nell Duke and David Pearson 2002) conducted a series of studies of the use of informational texts at the primary school level. These studies addressed an important instructional deficiency identified in earlier work in which Nell Duke (2000a) reported a scarcity in the use of informational texts at the primary grade levels. In related work, Nell Duke and David Pearson (2002) reported the results of studies addressing use of informational text in building reading comprehension (see also Maniates and David Pearson 2008; Pearson and Fielding 1995). In related research, Annemarie Palincsar and her colleagues (Hapgood et al. 2004; Hapgood and Palincsar 2007; Magnusson and Annemarie Palincsar 2003; Annemarie Palincsar and Magnusson 2001) conducted studies investigating the interdependency of hands-on activities (first-hand investigations) and related reading focused on the same or similar science concepts (second-hand investigations) on student science and literacy performance.

Another important series of research studies by Guthrie and his colleagues (Guthrie and Ozgungor 2002; Guthrie et al. 2004a, b) demonstrated consistent improvement in student reading comprehension and motivation to learn resulting from embedding multi-week, science-focused instructional modules into traditional reading programmes using their Concept-Oriented Reading Instruction (CORI) model. In a broader instructional intervention implemented in classrooms with a majority of K–6 ELL students for whom science instruction replaced traditional reading/language arts, Klentschy (2003, 2006) showed that grade 6 students who participated in the initiative for 4 or more years previously averaged a percentile rank (NPR) of 64 on the nationally normed Stanford Achievement Test in reading. And, Romance and Vitale (1992, 2001, 2008) found that replacing traditional reading/language arts instruction with in-depth science resulted in both higher reading comprehension and science achievement for students in grades 3–5 using nationally normed tests. Finally, in complementary work, a series of analyses by Hirsch (1996, 2006) addressed the cumulative learning of academic content as a major systemic deficiency in US elementary schools.

Major Interdisciplinary Implications Linking Science Instruction and Literacy: Grades K–5

The interdisciplinary perspectives presented in earlier sections have significant implications for educational policy and practice across grades K–5. The idea of knowledge-based instruction in science through a grade-articulated, core-concept-oriented curriculum provides a framework for potentially addressing literacy development within science. Such a knowledge-based curricular framework would provide the degree of cohesive structure that is necessary to insure that the science instructional strategies used in classrooms result in cumulative, meaningful learning in a manner that also engenders literacy development. Although these interdisciplinary perspectives are applicable to any curricular content area, this section summarises their combined implications in the form of eight ‘principles’ that form the foundation for the linkage of science and literacy instruction:

1. Use the logical structure of concepts in the discipline as the basis for a grade-articulated curricular framework.
2. Insure that the curricular framework provides students with a firm prior knowledge foundation essential for maximising comprehension of ‘new’ content to be taught.
3. Focus instruction on core disciplinary concepts (and relationships) of a domain and explicitly address prior knowledge and cumulative review.
4. Provide adequate amounts of initial and follow-up instructional time necessary to achieve cumulative conceptual understanding emphasising ‘students learning more about what they are learning’.
5. Guide meaningful student conceptual organisation of knowledge by linking different types of instructional activities (e.g. hands-on science, reading comprehension, propositional concept mapping, journaling/writing, applications) to those concepts.
6. Provide students with opportunities to represent the structure of conceptual knowledge across cumulative learning experiences as a basis for oral and written communication (e.g. propositional concept mapping, journaling/writing).

7. Reference a variety of conceptually oriented tasks for the purpose of assessment in order to distinguish between students with and without in-depth understanding (e.g. distinguishing positive vs. negative examples, using IF/THEN principles to predict outcomes, applying abductive reasoning to explain phenomena that occur in terms of science concepts).
8. Recognise how and why in-depth, meaningful, cumulative learning within a content-oriented discipline provides a necessary foundation for developing proficiency in reading comprehension and written communication.

Research Into the Effect of Integrating Literacy Within Knowledge-Based Science Instruction

While the preceding studies involved the general linkage between science and literacy, this section reviews in expanded fashion two different multi-year models that have taken a broader approach by replacing (vs. enhancing) regular reading/language arts instruction with in-depth science instruction in which reading comprehension and writing are integrated. These two models are the *Valle Imperial Project in Science* (Klentschy 2003, 2006; Klentschy and Thompson 2008) and *Science IDEAS* (Romance and Vitale 2001, 2008). Both models have demonstrated that using in-depth science instruction as a means for improving student literacy (reading comprehension, writing) is consistently more effective than the traditional basal reading/language arts programs presently endorsed by the majority of elementary education practitioners, policy makers (see Reading First Impact Study Interim Report, Gamse et al. 2008) and reading experts in academic settings. Moreover, each of these comprehensive models incorporates the eight major instructional principles based on interdisciplinary perspectives for integrating literacy within science instruction and offers significant implications for curricular policy that would also enhance time allocated to science in K–5 classrooms.

Valle Imperial Project in Science (VIPS)

VIPS Program Overview

Working with primarily Hispanic students in Imperial County, located in the southeast corner of California along the US border with Mexico where 50% of students are ELL, the VIPS science instructional model emphasises five interrelated elements necessary for effective systemic reform (National Academy of Science 1997): (a) a high-quality curriculum; (b) sustained professional development and support for teachers and school administrators; (c) materials support; (d) community and top level administrative support; and (e) programme assessment and evaluation. Within this framework, the design of the VIPS model links science and literacy through the use of student science notebooks within an inquiry-based approach to science instruction in which students are provided with an opportunity to develop ‘voice’ in their personal construction of the meaning of science phenomena. In the VIPS model, the student ‘voice’ is represented through the science notebooks that students use during their science learning experiences as a repository for reflections and as a knowledge-transforming (vs. storytelling) tool for constructing meaning. As a means for engendering significant growth in student achievement in both reading, writing and science (Amaral et al. 2002; Jorgenson and Vanosdall 2002; Saul 2004; Klentschy 2003; Klentschy and Molina-De La Torre 2004), the extensive use of science notebooks linking science and literacy has been a major contributor to the success of the VIPS programme.

In order to construct models through the workings of written language, children must necessarily interact with people and objects in their environment. Within the instructional environment established by the VIPS model, students use writing (and drawing) as a means for simultaneously constructing and reflecting on their understanding of science phenomena. This general view of the dynamics of student learning establishes a foundation for teaching in which children learn science by doing science and then use writing as part of their science experiences. This suggests that – in the context of science activities – student-produced science notebooks promote the use of literacy while clarifying students’ emerging theories about science phenomena (see also Hand et al. 2004; Norton-Meier et al. 2008). Student science notebooks provide not only stability and permanence to children’s work, but also purpose and form.

VIPS Research Findings

A major research focus of the VIPS science model has been documenting the relationship between the levels of student achievement (reading, writing, science) and the number of years of student participation in the VIPS science model. Recent studies reported by Klentschy (2003, 2006) involved students who had been enrolled in the El Centro School District for a 4 year period. Students in grade 4 and grade 6 were formed into groups based on the number of years (0–4) during which they experienced VIPS science instruction from project-trained teachers using the VIPS standards-based instructional science materials. The reading and science achievement measures used in the study were obtained from a district-wide administration of the Stanford Achievement Test (SAT) in Reading and Science. Student achievement in writing (only in grade 6) was assessed through a District-developed Writing Proficiency Test that used prompts requiring specific types of writing.

For reading, Stanford Achievement Test (SAT) reading achievement scores increased linearly over years of VIPS participation (from 0 to 4 years) for grades 4 and 6 students. Contrary to the achievement drop that is commonly found at the fourth-grade level (Chall and Jacobs 2003; Hirsch 2003), students in the VIPS model for 4 years (i.e. grades 1–4, grades 3–6) displayed levels of SAT Reading achievement that were above grade level (grade 4 mean NPR = 57, grade 6 mean

NPR = 67) based on national norms. For science, the results showed that Stanford Achievement Test (SAT) science achievement scores also increased linearly over the years of VIPS participation (from 0 to 4 years) for grade 4 and grade 6 students. Again, contrary to the achievement drop that is commonly found at the fourth-grade level, students in the VIPS model for 4 years (i.e. grades 1–4, grades 3–6) displayed levels of SAT Science achievement that were above grade level (grade 4 mean NPR = 53, grade 6 mean NPR = 64) based on national norms. Finally, for writing achievement, assessed through a district-developed test, proficiency for students in grade 6 also increased linearly with the number of years of VIPS participation. Students in the VIPS science model for 3 or for 4 years displayed a high degree of writing proficiency (91% and 89% pass-rates, respectively), reflecting the VIPS emphasis on meaningful writing.

Conclusions and Related Findings: VIPS

Overall, the results suggest a substantial relationship between the number of years of participation in the VIPS science model and achievement in reading, writing and science. These findings are consistent with those reported by Ted Bredderman (1983) in an analysis of 57 research studies of the learning effects of science programmes that emphasise in-depth learning relative to traditional textbook programmes. In that study, Bredderman reported a 14-percentile point difference in favour of in-depth (inquiry-based) programmes, along with consistent positive effects for females, economically disadvantaged students and minority students. In the VIP studies, students who did not participate in VIPS science during the years covered by this study (i.e. students with 0 years of participation) typically received instruction from science textbooks or from individually developed teacher units. The results of the VIPS studies also are consistent with a meta-analysis of 81 research studies by James Shymansky and others (1990), which contrasted the performance of students in hands-on, activity-based programmes with that of students in traditional textbook-based programmes.

At the same time, in interpreting the results of these meta-analyses, it is important to note that more recent complementary research findings (e.g. Magnusson and Annemarie Palincsar 2003; Palincsar and Magnusson 2001; Swan and Guthrie 1999) have emphasised that the integration of hands-on science activities with reading and writing, rather than hands-on science alone, was associated with increased student achievement. In fact, as a major characteristic of the VIPS (and Science IDEAS) model, the integration of literacy within science (vs. use of basal reading/language arts programmes) explains the combined overall impact of programme participation, resulting in both improved science achievement and the transfer of the VIPS science experiences by students to an overall improvement in reading and writing.

As VIPS students advanced through the grade levels, participation in VIPS science instruction has had other cumulative effects. For example, Klentschy and Molina-De La Torre (2004) found that more students in the district were enrolled in high school chemistry and physics classes than in any previous year, and that reading achievement at the high school level had improved incrementally with each succeeding high school freshman class over a 3-year period. In addition, they found that the cohort of students in high school in 2004 had the highest graduation rate in a decade.

Science IDEAS Model

Science IDEAS Programme Overview

The research on Science IDEAS model was conducted in large, highly diverse, urban school settings in south-eastern Florida (e.g. African American = 36%, Caucasian = 38%, Hispanic = 21%, other = 5%, free lunch = 37%). Science IDEAS is a cognitive-science-oriented instructional intervention that was initially validated within a grade 4 upper elementary setting (Romance and Vitale 1992). Implemented through a daily 2-hour block of time which replaces regular reading/language arts instruction, Science IDEAS is an integrated instructional model that embeds reading and writing within science instruction. In Science IDEAS, multi-day science lessons engage students in a variety of instructional activities (e.g. inquiry-based/hands-on science, reading text/trade/Internet science materials, writing about science, science projects, journaling, propositional concept mapping as a knowledge representation tool), all of which focus on enhancing science conceptual understanding. As an instructional intervention implemented within a broad inquiry-oriented framework (e.g. all aspects of teaching and learning emphasise learning more about what is being learned through text and non-text modalities), teachers use core science concepts and concept relationships (which students master to develop in-depth science understanding) as curricular guidelines for identifying, organising, and sequencing all instructional activities. From a curriculum integration standpoint, as students engage in science-based reading activities, teachers guide and support reading comprehension (and writing) in an authentic fashion.

As a simplified illustration of how Science IDEAS functions as a strong knowledge-based instruction model, Figure 87.2 shows how a propositional concept map (see Romance and Vitale 2001) representing the concept of evaporation could serve as a knowledge-based framework for organising and sequencing complementary instructional activities. Within the knowledge-based curricular framework representing the concept of evaporation, teachers identify additional reading, hands-on projects and writing activities to expand in-depth science knowledge.

The foundations of the Science IDEAS model are well-grounded in cognitive science (see Romance and Vitale 2001, 2008). Curricular mastery is considered as equivalent to knowledge-based expertise, and the cumulative development (and subsequent access) of curricular prior knowledge is considered to be the most critical determinant of success in meaningful learning across all varieties of instructional tasks, including reading comprehension.

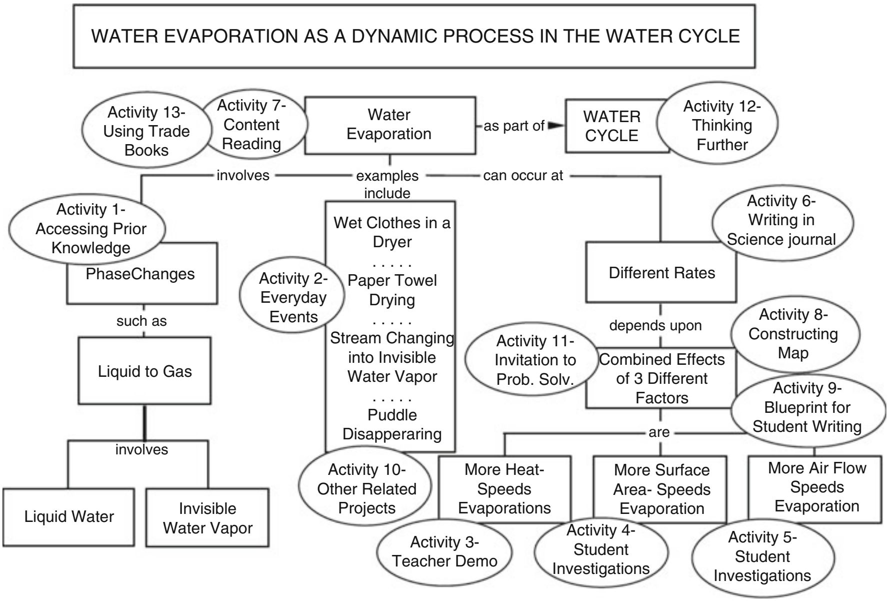

Fig. 87.2 Simplified illustration of a propositional curriculum concept map used as a guide by grade 4 Science IDEAS teachers to plan a sequence of knowledge-based instruction activities

Using the initial findings (Romance and Vitale 1992) as a foundation, the Science IDEAS model subsequently was extended to over 50 classrooms and 1,200 students across grades 3–5, which included ethnically diverse student populations and a variety of academic levels ranging from above average to severely at-risk. Most recently, the Science IDEAS research group is engaged in a multi-year project funded by the National Science Foundation (NSF) to develop, implement and study the process of scaling up the model both at the upper elementary level and, in a complementary fashion, adapt the grade 3–5 model to the primary level (grades K–2). Currently, the Science IDEAS model is being implemented in grades K–5 on a school-wide basis in 12 elementary schools.

Science IDEAS Research Findings

The research completed from 1992 to 2001 consisted of a series of studies conducted in authentic school settings, typically over a school year. In the first study (Romance and Vitale 1992), three average-performing grade 4 classrooms implemented the Science IDEAS model over the school year with their end-of-year achievement being measured by the ITBS Reading and the MAT Science. Results showed that Science IDEAS students outperformed comparison students by approximately 1 year's grade equivalent (GE) in science achievement (+0.93 GE) and one-third of a GE in reading achievement (+0.33 GE). In the second study conducted the following school year, Science IDEAS was again implemented with the same three teachers/classrooms in grade 4. In this replication, similar levels of achievement were found, with Science IDEAS students outperforming comparison students by +1.5 GE in science and +0.41 GE in reading (Romance and Vitale 2001).

In the third and fourth studies that followed (Romance and Vitale 2001), the robustness of the model was tested by (a) increasing the number of participating schools, (b) broadening the grade levels to grades 4 and 5 and (c) enhancing the diversity of participants by including district-identified at-risk students. Results of the year 3 study (Romance and Vitale 2001) were that low-SES predominantly African American Science IDEAS at-risk students in grade 5 significantly outperformed comparable controls by +2.3 GE in science and by +0.51 GE in reading over a 5-month (vs. school year) intervention. However, in contrast with earlier findings, no significant effect was found for the younger grade 4 at-risk students for the 5-month intervention.

In the fourth study, the number of participating schools and teachers/classrooms was increased to 15 school sites and 45 classroom teachers. The fourth study revealed that Science IDEAS students displayed greater overall achievement on both science (+1.11 GE) and reading (+0.37 GE). In addition, grade 5 students outperformed grade 4 students while, in a similar fashion, regular students outperformed at-risk students. But, unlike year 3, no interactions were found, indicating that the year-long Science IDEAS intervention was consistent across both grade levels (grade 4 and grade 5) and with both regular and at-risk students. In addition, in the final year of the expansion, the study addressed an important equity issue by showing that the differences in rate of achievement growth and affective outcomes in favour of the Science IDEAS participants were related only to programme participation and not to student demographic characteristics (e.g. at-risk, gender, race).

All of the preceding reported studies (1992–2001) focused on individual teachers/classrooms located in a variety of different school sites. However, beginning with 2002, the Science IDEAS research framework (supported by an IERI/NSF grant) was composed of two different initiatives. The primary initiative (Romance and Vitale 2008) involved implementing Science IDEAS on a school-wide basis in grades 3, 4 and 5 in an increased number of participating schools (from 2 to 12). The increased number of such school-wide interventions provided a framework for studying issues relating to scale-up of the Science IDEAS model (Romance and Vitale 2007; Vitale and Romance 2005; Vitale et al. 2006). The second initiative consisted of two smaller studies embedded within the overall scale-up project that explored extrapolations of the Science IDEAS model to grades K–2 (Vitale and Romance 2007a) and as a setting for reading comprehension strategy effectiveness (Romance and Vitale 2006).

Figure 87.3 shows the cross-sectional effect across grades 3–8 of the Science IDEAS model implemented school-wide in grades 3–8 on ITBS science and reading achievement across 12 participating and 12 comparison schools in 2006–2007 (Romance and Vitale 2008). Both groups of schools were comparable demographically (approximately 60% minority, 45% of students receiving free or reduced-cost lunch). In interpreting these figures, it should be noted that students in grades 6, 7

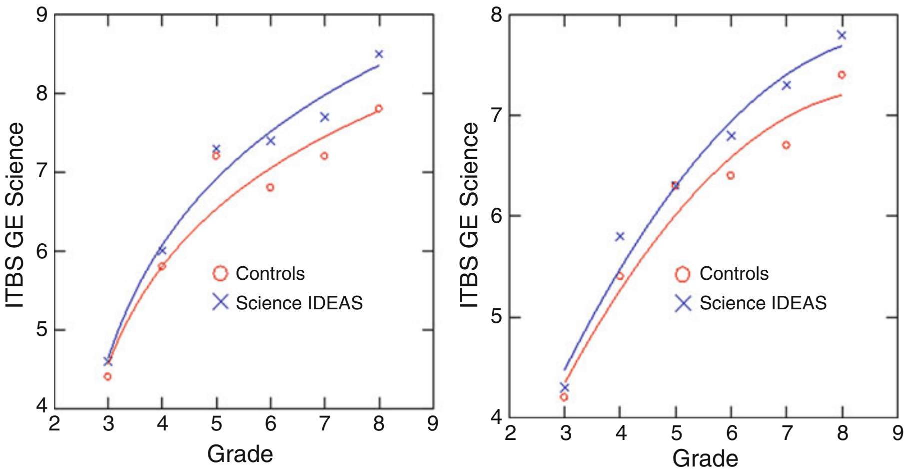

Fig. 87.3 2006–2007 ITBS achievement trajectories for Science IDEAS and control schools in science and reading across grades 3–8

and 8 (who had previously attended Science IDEAS or comparison schools) were categorised as extensions of the Science IDEAS or comparison school they attended in grade 5).

In interpreting achievement trajectories in science in Figure 87.3, linear models analysis revealed that Science IDEAS students obtained higher overall ITBS science achievement scores than comparison students (adjusted mean difference = +0.38 GE in science with grade-level differences ranging from +0.1 GE to +0.7 GE). Both the treatment main effect and the treatment-by-grade interaction were significant, indicating that the magnitude of the treatment effect increased with grade level. Co-variates were gender and at-risk status. In interpreting the achievement trajectories in reading shown in Figure 87.3, linear models analysis revealed that Science IDEAS students obtained higher overall ITBS reading achievement than comparison students (adjusted mean difference = +0.32 GE in reading, with grade-level differences ranging from 0.0 GE to +0.6 GE). While the overall treatment main effect was significant, the treatment-by-grade level interaction was not. Co-variates were gender and at-risk status. Other results of the analyses were that (a) the treatment effect was consistent across at-risk and non-at-risk students for both ITBS science and reading and (b) girls outperformed boys on ITBS Reading (there was no gender effect for science).

The second research initiative consisted of two small-scale studies embedded within the overall NSF scale-up project that explored extrapolations of the Science IDEAS model to grades K–2 and explored the effectiveness of in-depth science instruction as a setting for reading comprehension strategies. The objective of the K–2 mini-study (Vitale and Romance 2007a) was to adapt the grade 3–5 Science IDEAS model to grades K–2 in two Science IDEAS schools (vs. two comparison schools). Within the context of scale-up, the involvement of K–2 teachers/classrooms was designed to transform the implementation of the grade 3–5 model into a more comprehensive, school-wide instructional model. Unlike the grade 3–5 model, however, in grades K–2, teachers only incorporated 45 min of science instruction into their daily schedules while continuing their regular daily reading instruction. A year-long study revealed an overall main effect in favour of Science IDEAS students on ITBS science (+0.28 GE). However, for ITBS reading achievement, a significant treatment-by-grade level was found, and subsequent simple effects analysis showed a significant difference of +0,72 GE in grade 2 on ITBS reading, but no effect in grade 1. There was a significant effect of white vs. non-white (+0.38 GE), but no treatment-by-ethnicity interaction.

The objective of the grade 5 mini-study (Vitale and Romance 2006b) was to explore whether research-validated reading comprehension strategies (see Vitale and Romance 2007b) would be differentially effective in the cumulative meaningful learning setting established by Science IDEAS classrooms in comparison to a basal reading classrooms emphasising narrative, non-fiction reading. After a 7-week intervention in which reading comprehension strategies were implemented in Science IDEAS classrooms and basal reading classrooms in accordance with a 2 × 2 factorial design (with prior state-administered reading test scores as a covariate), the results showed that Science IDEAS students performed significantly higher than basal students on both ITBS science (+0.38 GE) and reading (+0.34 GE). Although the main effect of reading comprehension strategy use was not significant, the instructional setting-by-strategy use interaction was significant. Specifically, simple effects analysis showed the use of the reading comprehension strategy by Science IDEAS students improved their overall performance in both science (+0.17 GE) and reading (+0.53 GE), but strategy use had no effect in basal classrooms.

Conclusions and Related findings: Science IDEAS

The major conclusion from the multi-year pattern of findings is that Science IDEAS, as an integrated instructional model, was effective in accelerating student achievement in both science and reading in grades 3, 4 and 5. More importantly, the magnitude of the effects expressed in grade equivalents on nationally-normed tests (ITBS, SAT, MAT) was educationally meaningful. Because, in grades 3, 4 and 5, Science IDEAS replaces regular basal reading instruction, the effectiveness of the Science IDEAS model which emphasises in-depth, cumulative, conceptual learning offers major implications for curricular policy at the elementary levels (see Vitale et al. 2006). Of parallel importance is the finding that the effects of Science IDEAS in grades 3, 4 and 5 were transferable to grades 6, 7 and 8. Although this finding is presently being replicated, it has important implications for elementary curricular policy.

Complementing the preceding are other supportive findings that (a) the effect of Science IDEAS is consistent for both regular and at-risk students, (b) the adaptation of the model for use in grades K–2 is feasible and (c) Science IDEAS, in emphasising in-depth, conceptual learning, provides a more effective context for reading comprehension enhancement strategies than narrative-oriented basal reading materials. Overall, the multi-year research initiative involving Science IDEAS provides a strong pattern of evidence supporting the effectiveness of the Science IDEAS model, as well as the natural linkage of science and literacy (Romance and Vitale 2006, 2008).

Towards an Interdisciplinary Rationale for Expanding the Role of In-Depth Science Instruction in Elementary Schools

The preceding discussion suggests implications for policy and practice concerning the role of in-depth science instruction in elementary schools. These implications are counter to those of present school reform initiatives which, despite their limited success (e.g. Gonzales et al. 2008; Lee et al. 2007; Lutkus et al. 2006), continue to emphasise increased instructional time for traditional reading/language arts at the expense of science instruction (Dillon 2006; Jones et al. 1999). As noted in this chapter, there is an expanding consensus research base from science and literacy that linking in-depth science and traditional reading/language arts instruction jointly improves student achievement in both literacy and science. As also presented here, the interdisciplinary research foundations for such combined achievement results are well-established. Yet, despite consistent positive outcomes, the impact of interventions which only augment reading/language arts instruction with in-depth science are necessarily limited. Rather, consistent with interdisciplinary research foundations, comprehensive knowledge-based models which developmentally integrate reading/language arts within in-depth science instruction would promise to provide an instructional environment that is far more powerful.

In fact, the VIPS and Science IDEAS models overviewed here have accomplished such integration, as well as demonstrating both immediate and long-term achievement effects. In terms of immediate findings, both models have shown consistently that replacing traditional reading/language arts with in-depth science learning results in substantial student achievement acceleration in science, reading comprehension and writing. Moreover, both have reported positive transfer effects of in-depth science instruction from the elementary to secondary levels. Specifically, studies of Science IDEAS revealed that grade 3–5 students displayed greater achievement in science and reading comprehension in grades 6–8. And, VIPS studies demonstrated increased enrolment of students in high school science courses and subsequent graduation rates. In fact, such positive transfer effects from elementary-level instruction to secondary-level performance are contrary to findings reported in the literature (e.g. Dolan 2005). Building on a foundation of interdisciplinary research perspectives and findings, science education researchers and practitioners alike could have an opportunity to argue for systemic changes in present curricular policy to increase substantially the instructional emphasis on in-depth science instruction in grades K–5.

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Chapter 88
Writing as a Learning Tool in Science: Lessons Learnt and Future Agendas

Brian Hand and Vaughan Prain

Research over the last three decades on the role of writing in learning has sought to (a) identify what is or might be known and learnt by the writing process, and (b) explain how, and under what conditions, writing promotes learning. In the 1990s, two dominant accounts of the role of writing as a learning tool in science guided classroom research. The genrist approach (e.g. Veel 1997), drawing on cognitive processing theory (Johnson-Laird 1983), assumed that language organised and represented thought, and that students needed to be inducted into the language practices of science. In this way, generic knowledge of the form/function of science texts, once internalised by students, 'provides the basis for a new disciplined way of seeing and thinking' (Bazerman 2007, p. 8). From this perspective, knowing and reasoning in science depended on students' acquisition of subject-specific writing skills, evident in the writing practices of scientists (Halliday and Martin 1993). By contrast, advocates of a 'learning through writing' approach (e.g. Prain and Hand 1996), drawing predominantly on claims about effective conditions for learning, asserted that to acquire the new literacies of science, students needed to write in diverse ways for different readerships to clarify understandings for themselves and others. From this perspective, the communicative aspect of writing, entailed in constructing, organising and clarifying meanings for self and others, served multiple purposes rather than functioned mainly as representing resolved knowledge.

Both perspectives assumed that writing operated as an epistemological tool for learning, in that drafting and revising processes enabled students to build and review links between classroom activities, conceptual understandings and their expression. Both perspectives assumed that writing in science entailed making evidence-based

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claims about natural phenomena, and was therefore fundamentally about disciplinary reasoning in this subject. The genrist approach emphasised the necessity of fidelity to disciplinary norms of expression for learning to occur, whereas the writing-to-learn approach stressed personal meaning-making through links to natural language and everyday communicative contexts. Both claimed that classroom research using these approaches addressed epistemic concerns that tied student writing to the knowledge-production and representational practices of scientists, but differed about how this might best be facilitated in practice in schools.

In this chapter we review the lessons learnt from these two agendas as a basis for identifying current conceptions of the role of writing in science learning, where writing is now understood as one of several modes that need to be integrated to represent processes, reasoning and findings in this domain. We consider the implications for epistemological claims made for writing within these new accounts of modal interdependency, as well as emerging research agendas based on these new perspectives. We conclude by outlining future research questions that need to be addressed in this field.

Genrist Research

The genrist viewpoint assumes that the languages of science are broadly a stable, denotative, representational system that must be learnt in order for students to demonstrate science literacy. According to Martin (2000) and others, students will learn effectively the rules and meanings of the particular language practices of science through the following teaching strategies: detailed analysis of linguistic features of textual examples; joint construction of genres with their teacher; and through an explicit extensive teacher focus on key textual function/form relationships and their rationale. In other words, researchers within this orientation favour a highly directed, explicit teacher-focused pedagogy that emphasises the functional aspects of language features of this discourse.

Classroom research based on this perspective has largely taken the form of case studies of reputed desirable or exemplary implementation (e.g., Unsworth 2001). While this research has established increasingly complex accounts of the tasks learners face in understanding and mastering specific multi-modal genres, these studies have not assessed contrasting treatments, and have, therefore, not established a case for greater learning gains for this approach over others. The evolving nature of functional dimensions of web-based science texts has further complicated genrist attempts to move beyond descriptive accounts of these texts to meta-functional principles. Supporting this genrist orientation, Unsworth (2006, p. 72) posed the rhetorical question of whether 'any sustainable arguments' could be made for 'a positive relationship between knowledge about texts … and increased effectiveness in some aspect of textual production'. While assuming that only an affirmative answer was sensible, this question raises further questions about how much and what kind of formal knowledge might enhance learning, and what developmental stages of understanding might be appropriate for different levels of schooling. At the same time that genrists were advocating the value of student explicit formal knowledge of text structures, recent research in cognitive science on strategies and practices that enable learning has asserted that learners employ a richer range of both formal and informal interpretive meaning-making strategies. In summarising this diverse literature, Klein (2006) listed the following as significant strategies students use to learn: their perceptions, motor actions, feelings, embodiment, use of analogy and metaphor, pattern identification and completion in experiences or texts.

Writing to Learn Science Research

Researchers within this perspective, such as Levin and Wagner (2006) assert that students, in striving to clarify networks of concepts in science topics, should be encouraged to write in diverse forms for different purposes. Descriptive studies where diversified science writing tasks have been used have reported positive effects on students' attitudes towards, and engagement with, the subject. Comparative studies of contrasting treatments have been conducted by Hand and his colleagues around diversified writing types, including the use of a framework called the Science Writing Heuristic (Hand 2007). This framework of a modified laboratory report structure leads students through a reiterative process of knowledge construction in science through a focus on making and justifying claims, gathering and representing evidence, and reflecting on the progression of ideas. Gunel et al. (2007) noted that using writing-to-learn strategies was advantageous for students compared to those students working with more traditional science writing approaches. In another study Gunel et al. (2004) reported that students' performance in answering higher-order cognitive questions was enhanced when students used a modified writing genre, when contrasted with student use of the traditional laboratory report, although the teachers' implementation strategies were viewed as a major factor in this outcome. The researchers claimed that writing serves learning when (a) writing tasks are designed to require students to focus on conceptual understanding, and also require students to elaborate and justify these understandings of the topic, (b) the target readership is meaningful for the students, (c) students are provided with sufficient planning support, and (d) planning activities engage students in purposeful backward and forward search of their emerging texts.

Implications of These Research Agendas

These two perspectives have provided useful insights into (a) the complexity of the demands of writing tasks in science, and (b) likely conditions to promote learning through writing. The genrist emphasis on student induction into the representational norms of this subject is broadly accepted as a necessary condition for developing student competence in science. However, this research, in highlighting the increasing complexity of these norms (now also entailing new technologies for conducting and representing scientific reasoning in the broader scientific community), perhaps provides a partial answer to the question of why so much student learning in this subject is superficial and struggles to achieve deeper understanding. Making this induction into science engaging and meaningful rather than perfunctory or rote requires a rich range of learning opportunities of the kind the writing-to-learn research has sought to identify. This agenda has demonstrated learning gains in some contexts, but makes far more demands on teachers than genrist methods and sits uneasily with some disciplinary expectations about appropriate learning/testing/writing tasks in this subject. Some of this research has focused on student writing as a meta-cognitive tool for reflecting on meaning-making in science (Hand 2007), but this raises further questions about what exactly students can know through this process, and which writing tasks repay the effort of this kind of student work.

Writing Within Multiple Modes of Representation in Science

Both agendas assumed that writing was the dominant learning mode, whereas more recent research has focused increasingly on modal interdependence in interpreting and constructing science texts. Lemke (2004, p. 41) noted that students needed to 'integrate multiple media simultaneously to reinterpret and recontextualize information in one channel in relation to that in the other channels', with students having to translate, integrate and reinterpret meanings across verbal, visual and mathematical expressions, as well as connect these modes to earlier experiences of science activity. This is evident when students interpret the individual and relational meanings between a diagram, an accompanying text, and its referents in the world. Equally, students participate in similar processes when they construct their own text to clarify or elaborate on the meaning of an accompanying graph, photograph or diagram. For Lemke (2008, p. 2), writing's forte is its capacity to enable 'reasoning about relations among categories' because it operates primarily by categorical contrasts and exclusions. Quantitative meanings such as rates and angles of change, and alterations to shape and motion are more suited to visual and mathematical representation. In this way, Lemke argues that science is necessarily about reasoning across interdependent modes of measurement and explanation. He further argues that the use of natural language, and by implication writing, enables links to be made between qualitative observation and linguistic reasoning about verbal categories, concepts and their justification.

In commenting on the epistemological role of language, and by implication writing, in learning, Anderberg et al. (2008) argued for the dynamic and ambiguous character of the relations between students' meanings, conceptions and expressions. They note that reproducing disciplinary language does not ensure disciplinary understanding, and that students' intended meaning for an expression is often arbitrary, associative and contextual rather than convention-dependent, concurring with Klein's (2006) account of strategies learners use to make sense of new ideas. Anderberg et al. (2008) assert that for language to serve learning, students must reflect explicitly on the adequacy of the links they are making between intended meanings, conceptions and different or diverse expressions. These researchers further note that this use of language as a knowledge-constituting activity is a developmentally recursive process. Students need to reflect on the ways they change or develop intended meanings and to recognise the same meaning across different contexts, different conceptions and different expressions and modes. For Anderberg et al. (2008), these understandings can be developed through teacher-guided conversations and student reflection that explicitly address these issues. They further assert that students are likely to proceed through a sequence of understandings that starts with isolated local lexical meanings, and superficial relationships between meaning and expression, and develops into more holistic, integrated linkages between concepts, their expression and their referents. By implication, the capacity for student writing to function as an epistemological tool depends on the robustness and coherence of these links.

Findings from Literacy Research on Writing

Various recent meta-analyses and reviews have sought to identify major strategies that assist students to improve their writing. While not focused explicitly on learning in science, these studies point to composing strategies that have been shown to improve students' writing quality. Graham and Perin (2007a, p. 445) highlighted 11 different interventions that resulted in a range of effect size gains. These include explicit drafting instruction (0.82), summarisation (0.82), peer assistance (0.75), setting product goals (0.70) and word processing (0.55). This analysis also identified a negative effect size for grammar instruction (−0.34), suggesting that grammar instruction as a predominant focus does not appear to be highly beneficial for students. In summarising their findings they posit a number of critical features that need to be carefully considered, particularly as we look to translate these for use within science classrooms. Graham and Perin (2007a, p. 447) suggest that students need to be engaged with:

1. Strategies for planning, revising and editing their compositions
2. Need to develop instructional arrangements in which students work together to plan, draft, revise and edit their work
3. Set clear goals including the purpose for the writing and the characteristics of the final product
4. Make it possible for students to use word-processing tools
5. Involve students in writing activities that sharpen their skills of inquiry
6. Engage students in writing activities that help them gather and organise their ideas

While the first three points relate to routine procedural support in generating and revising a text, the final two points imply that appropriately framed writing tasks can enable students to practice formal and informal reasoning skills as they sort, link and justify their emerging ideas (Graham and Perin 2007b), that writing can enable new insights and knowledge, and thus function epistemologically. However, as Graham and Perin (2007b) indicate, the number of studies focused on writing to learn strategies is limited, and their review leaves open the question of what kinds of writing tasks will promote this new knowledge.

Kellogg (2008), drawing on the perspective of the professional writer, claimed that writing is a complex activity that needs much deliberate practice in order to develop the necessary 'executive control over cognitive processes so that one can respond to the specific needs of the task' (p. 2). He suggests that instead of the two cognitive stages as posited by Bereiter and Scardamalia (1987), that of knowledge telling and knowledge transforming, there is in fact a stage of knowledge crafting. In the knowledge crafting stage, 'the writer shapes what to say and how to say it with the potential reader in mind. The writer tries to anticipate different ways the reader might interpret the text and takes these into account when revising it' (Kellogg 2008, p. 7). To reach a proficient level requires the use of deliberate practice where the writer takes many years to use effectively working memory to take account of all situations, much like that of a musician or athlete who is proficient.

However, Galbraith et al. (2007) state that such an approach does not capture the 'more deliberate components of the writing process' (p. 4), and in fact focuses on the more explicit thinking processes rather than on the implicit processes that are 'closely linked to text production itself' (p. 4). They suggest we need to consider writing not as a one-way process between planning and translating into text, but rather as a two-way interaction between reflection and text production. From this perspective, writing is not purely a linguistic process but one that involves 'content generation closely tied to the formulation of thought in language' (p. 4). Expanding on this idea, Klein et al. (2007) suggest that text production plays an independent role in developing a writer's understanding: it is not just about writer's planning strategies. They suggest that there are two other critical activities that students need to engage with, namely meta-cognitive (or reflective) processes and reviewing of experimental data. In providing a translation of these activities in terms of school classrooms they suggest that students need to be 'encouraged to use writing to develop new ideas, rather than to simply record ideas that they already have', 'encouraged to review sources frequently, and to use them as a resource for generating ideas and language', and 'encouraged to reread their texts and evaluate them critically' (p. 217). Engaging students in such activities would require them to move beyond procedural skills to use writing as a vehicle for deeper knowing, that is, to function as an epistemological tool.

Supporting such a position, Lavelle (2007) highlights the characteristics of deeper engagement that such writing can enable. These include meta-cognition, reflection, engagement, authorship, agency, audience awareness, revision and transformation (going beyond the assignment). Such characteristics reflect a position that entails more than surface understanding, and points to an alignment between idea generation and self-investment in the process. This writing requires an individual to engage in a range of high-level cognitive and meta-cognitive activities in the act of generating new meanings.

Pedagogical Practices Needed

Currently there is considerable interest in how to translate these theoretical accounts of the potential of writing to inform practices in science classrooms within the K–12 settings, with increasing agreement that writing tasks should include making or refuting evidence-based claims (see Moje 2007). Klein (2006) raises two critical issues that need to be addressed when examining the requirements for using writing as an epistemological tool within science classrooms. The first deals with the relationship between non-linguistic (multi-modal) representations, such as very basic number sense and visual–spatial ability, and language (written text). He suggests that non-linguistic knowledge can be implicit, or explicit, 'that is, conscious, but non-verbal' and that 'transforming this non-linguistic knowledge into language appears to facilitate increased awareness, critical appraisal and transfer to new tasks' (p. 154). While recognising the difficulties associated with articulating non-linguistic knowledge, he believes that it will be useful to students to be provided opportunities to engage in the process. However, he cautions that construction of such a text needs to reflect and bridge both the individual cognition required of the task and the mediating collective knowledge-building process undertaken in production of a science text.

The second issue is the need to reconcile past cognitive science views of thought and language as purely denotative and more recent perspectives that view them as also entailing an expressive function, a view shared by Anderberg et al. (2008). For Klein (2006, p. 171) there is a need for students to move 'between everyday, narrative speech and scientific explanation and argumentation by combining talk and writing.' Students need to write 'informal, speech like texts and narrative-argument blends' making sure to retain the pragmatic and dialogical aspects in argumentation as well as being taught 'science text genre' (p. 171). In summary, students need opportunities to move between multiple modes of representations, articulating these through language opportunities that allow for transition between everyday language and the language of science. Such opportunities will by necessity involve narrative forms that allow students a chance to clarify fuzzy thinking to build understanding of the denotative concepts of science.

To translate this theoretical perspective of Klein into pragmatic reality within science classrooms, Prain and Hand (1996) proposed a writing to learn framework for use by teachers. The framework consists of five elements: method of text production (e.g. pairs, computers, etc.), audience, purpose, type of text, and topic. In constructing the framework, the researchers highlighted a number of essential features that teachers need to be aware of. These include the concept of authentic audience. Unlike Kellogg's postulation that students struggle to understand audience factors because these are always imagined, Prain and Hand stress the importance of writing to real audiences. Such audiences include peers, younger students, parents, and the general public. Another feature is that the element of topic is centred on the 'big ideas' of the topic rather than the factual elements of the topic. They believe that the students need to write about the central organising ideas of the topic, as this will require them to have to engage with examining the relationship between all the content elements of the organising ideas. The framework is not prescriptive as the researchers recognise that each classroom is unique and that the knowledge and language forms used are unique to that group and thus the writing task(s) needs to be framed for that particular group, that is, how students engage the language and cognitive tasks entails both expressive and denotative dimensions. Klein (2006) suggests the addition of sources as a sixth element, as students are constantly examining and valuing information from a range of different sources.

In adding to the discussion about pedagogical strategies, Tynjala et al. (2001, p. 16) suggested that when constructing writing-to-learn tasks for students, there are a number of important conditions that need to be met. These include: writing tasks should promote active construction; tasks should make use of students' previous knowledge and existing conceptions; tasks should encourage students to reflect on their own experiences and conceptualise explanations about them; tasks should involve the students in applying theories to practical situations; and tasks should be integrated into classroom discourse and other school work. For these researchers the writing tasks should be viewed as knowledge-transforming or knowledge-constituting activities rather than reproductive tasks. Students should undertake writing tasks that are more than recall activities. For Furtak and Ruiz-Primo (2008), this means that students need to be engaged with writing tasks that push them to evaluate, integrate and elaborate knowledge in new ways.

Kieft (2006) further highlights a number of concerns that teachers need to be aware of when using writing approaches in their classrooms. From the epistemological perspective she points out that the results from her research group suggest that students vary in their use of planning and revision as writing strategies. There is not a 'one size fits all' model and teachers need to be aware of the students in their classrooms and provide appropriate opportunities where necessary. Some students benefit from spending time planning before writing, while others benefit from revising their initial texts rather than spending time planning. Kieft also highlights the need for teachers to 'pay more attention to the combination of writing and learning, by providing writing instruction when writing-to-learn, and providing interesting and challenging subjects to write about when learning-to-write' (p. 85). The importance of this statement is that teachers need to be aware of the necessity to provide 'just in time' instruction where needed when using different writing types, audiences and purposes for tasks within their classrooms.

Conclusions and Future Research

The increased focus in recent science education research on modal complexity and interdependence has led to a decreased attention to the role of language and writing in learning. While acknowledging the centrality of this interdependence in science learning, we have argued in this chapter that writing can play a critical role in knowing and learning in this subject. As an epistemological tool, writing can serve multiple purposes, including functioning as a knowledge-constituting process (Anderberg et al. 2008), and enabling students to refine and organise claims about key concepts and processes in and across topics. It can also function as a meta-cognitive space for reflection by students about their own learning, as well as enabling them to characterise conceptual linkages between modes when they embed different modes within a written text. It also has the potential, as noted by Lemke (2008) and Klein (2006), to deepen students' understanding of the semiotic resources of science as a multimodal discourse. For student writing to achieve these outcomes various pedagogical principles need to be enacted. These include sufficient procedural guidance to enable students to tackle the kind of writing tasks outlined in the previous section. In conceptualising this teaching and learning framework, the teacher needs to consider what goals, support and classroom context will provide a basis for student knowing and learning through this writing. However, in emphasising the epistemological function of writing teachers need to be orientated towards tasks that require students to be involved in the conceptualising and construction of text, rather than simply responding to teacher-driven demands or imposed tasks.

Future research in this area needs to identify the learning effects of different writing tasks where students pursue varied purposes for different readerships. For example, there is a need for more research on the effects of writing tasks where students are expected to embed non-verbal modes within a text as part of demonstrating adequacy and fluency in making a scientific claim. Other research could focus on the effects of different modal sequences when engaging with a new topic or when re-representing conceptual understanding of that topic in a subsequent text. Further research also needs to focus on identifying topic-specific, and grade-appropriate, writing tasks that foster learning experiences where writing functions as an enhanced way of knowing and reasoning in science.

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Chapter 89
The Role of Language in Modeling the Natural World: Perspectives in Science Education

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The main purpose of this chapter is to review science education research studies on models and modeling with the focus on language as a central mediator of science learning. We have tried to highlight the theoretical influences that support the research work reviewed, influences that are supported mainly by views of language, science, and models. We have also attempted to incorporate recent trends in the development of the field and have sketched a model-based view of school science as an autonomous activity.

Science education has long been interested in the role of language in science teaching and learning in the classroom. However, in this review we would like to focus on research that has analyzed in depth the role of language in knowledge construction in the classroom. The various researchers who have studied this area each have different theoretical orientations and analytical traditions that have established a fruitful dialogue with other disciplines such as linguistics, philosophy of science, and cognitive psychology.

In the present review, we have included not only the work of well known researchers, but also the work of those researchers who do not make their position on language or modeling explicit, but whose contributions are relevant for the purpose of this review. We have included not only articles dealing with theoretical aspects of models and modeling in science education or language, but also research reports. We have tried to keep a geographical and cultural balance of authorship in the selected articles. In addition, we have tried to cover a range of underrepresented science education research journals, such as the French journals *Didaskalia* and

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Aster, and the Spanish journal *Enseñanza de las Ciencias*. The remaining journals are English-language journals published in Europe, North America, and Australia. All of the reviewed studies show a strong commitment to the content of science education and to the need for science to be an important reference for science education.

The research work reviewed focuses on a meeting point between two frameworks: the views of language and the views of science that encompass models and modeling. The following paragraphs describe our attempt to sketch the evolution of these two frameworks.

Evolution of Science and Language Views: A Crossroads of Frameworks

Evolution of Scientific-Model Views

A chapter in the first edition of the *International Handbook of Science Education* on models and modeling was important since it provided a clear explanation of the research that was being done by many European science education researchers (Gilbert and Boutler 1998). The authors' position was that there was a consensus in the community on the concept of "model." We would like to depart from this work and show that the science education research work using models as basic constructs does not reach the same conclusion.

There are still debates within the scientific and epistemological communities about the meaning and scope of the term "model." However, all members of both communities agree that the model is a "substitute" or "subrogate" of real systems being studied. The complexity of these systems makes it impossible to use them scientifically; instead, scientists work with "representations" of these systems that retain only certain essential aspects. That is why models act as facilitators for understanding the real world.

Different philosophical traditions have approached the role of models and their relationship to theory and reality in a very different way. This chapter explains the changes in what science is and how models are conceptualized. Our approach is based on the philosophy of science and its epistemological focus on the relationship between theory, models, and reality. Taking into consideration the work of Koponen (2007) we are acknowledging the need to introduce the philosophy of science as a framework influencing science education.

The Received View of Science

Philosophers of science at the beginning of the twentieth century were drawing a picture of science based on the a priori value of logic and mathematics. Science was seen as a unified field, deriving from physics, which used a universal language.

The language of science was thus governed by logic and mathematics, with a strong rational component. Influenced by logical positivism and critical rationalism, this tradition introduced scientific theory as the focus for reflection and thus the most important component of science. Models were secondary constructs within the building of science. A distinction was made between models from the formal sciences, such as mathematics, and models from the natural sciences, such as physics, biology, and chemistry. In the formal sciences, models were considered to be representations of theories and acted as systems that followed all the axiomatic requirements of the theory. Models were cases of theories; they were interpretations of theory which were mixed up with it. In the natural sciences, however, models were considered the result of the interpretation of natural phenomena. They were usually concrete, simplified representations of complex systems typically found in natural phenomena.

The New Philosophy of Science

The received view of science became problematic since it left out the scientist and the social contexts. The influence of history on the philosophy of science shed light on other aspects of science and represented a step toward conceptualizing science as a social activity. The monolithic view of science that characterized the previous school of thought began to fragment, until the diversity of methods and languages used among different scientific disciplines were recognized. These focus on the particular and the contextual, and therefore on the diversity of the scientific disciplines, allowing Thomas Kuhn (1965) to propose a new concept for the model. He introduced the idea of the exemplar, which acted as a model in a particular case of a particular discipline. This idea of the model exemplar is important since it recognizes that theory and phenomena require something else in order to be related to each other: successful encounters, or exemplars, which can be considered models. Models are thus concrete cases that have been resolved successfully by the theory. Although his efforts were not fully recognized, Kuhn contributed to introducing a hybrid idea of the model that associated theory and phenomena in the same construct.

The Semantic View of Science

The semantic view of science is at present a solid tradition within the field of philosophy of science, and more precisely in epistemology. This view was strongly influenced by the cognitive shift that characterized all social sciences at the end of the twentieth century. The cognitive sciences are interested in the emergence of human knowledge and its relationship with human activity, including its linguistic, instrumental, and volitional dimensions. This school of thought holds a semantic view of theory in that it focuses on the meaning of theories rather than on its syntax, form, or structure. Models become central constructs for thinking about science within this school. They are projections of theory into the world in order to make it possible for the models to be realized. Facts thus become paradigmatic, since they are privileged phenomena that can be successfully interpreted through models. Models can be expressed through a variety of languages, and the words used to do so do not have a universal meaning, as was the case with the received view of science. Scientific terms are created in scientific activity.

Izquierdo-Aymerich and Adúriz-Bravo (2003) identified several characteristics to describe models within a semantic view of science: (a) models focus on the semantic, pragmatic, and rhetoric aspects of the language rather than on the logic and formal structure of language; (b) scientific theories are not only a collection of propositional statements, but also a collection of the facts that are interpreted by the theory; (c) scientific theories are sets of models, which become the core construct for the understanding of scientific knowledge; (d) models stand as mediators between what is said and what is experienced; and (e) there is a wide range of equally valid languages to express scientific models.

Within the semantic tradition, Giere (1988) is a strong proponent of what he calls a cognitive view of science. He develops a definition of the scientific model that has important consequences for science education as seen in the adaptations made by several authors (e.g., Develaki 2007), that has important consequences for science education. A scientific model is any representation, using any symbolic means, which allows one to think, talk, and act rigorously and in-depth on the system being studied. Thus, highly abstract models with images, tables, networks, etc., could be classed as scientific models provided that they enable activities such as describing, explaining, predicting, acting, etc.

The contributions of a cognitive view of science in science education have only just begun to be developed. One such contribution is to consider science learning as a process of knowledge emergence and to give it the status of a school science activity. This activity must be epistemologically founded according to the values and aims of the school science and must be designed as a convergence of thinking, acting, and talking about natural phenomena. In addition, this activity should create an appropriate context where students can transform everyday facts into scientific facts by also transforming everyday language into a language of science.

Evolution of Language Views

The role of language in science teaching and learning has evolved over the last few decades. Although language has always been present as a phenomenon, it is only in the last decade that it has become a strong focus in science education research. The first review on language in science education written by Sutton (1998) introduced two important views that are prevalent in the science education research community: (a) that language is a system for transmitting information; and (b) that language is an interpretive system for making sense of experience. Carlsen (2007), in a more recent review on language and science learning, included both views and added a third one: (c) that language is a tool for participation in communities of practice.

We have witnessed an important shift in the way to frame the role of language in science teaching and learning. There has also been a shift in the understanding of language in research on models and modeling in science education: language was previously understood as a means for transmission of information, but is now considered as an interpretive system of sense-making and as action and social action. We have chosen the three approaches presented in Carlsen's review and have used metaphors to label them: language is a medium; language is theory and action; and language is interaction.

Language is a Medium

Language is considered to be a representational medium that is independent of context and has no significant effects on thought or on one's perception of the world. Language acts as an interface between the world and the mind, between reality and people. Language, the words it uses, the form those words take, and their structure carry meanings from one place to another, from the field of expert science to the field of school science. It is considered a representational medium through which experience and ideas are expressed and thus private ideas or mental models are communicated. Language as a medium in science education is considered to be a specialized symbolic system that carries the meaning that needs to be learned.

The metaphor of medium suggests that most of the science education approaches that could be fitted in a transmissive model of teaching and learning would be included here. However, most of the conceptual-change literature, as Givry and Roth (2006) stress, is characterized by a conception in which language is a tool to make private knowledge public either for students or for teachers. What characterizes conceptual change in science education research is that conceptions are located somewhere in the mind of learners in a variety of forms, and that language is a means for expressing internal conceptions to the external world. The metaphor of language as a medium is used implicitly in many of the reviewed papers. Researchers interpret what students write or say as observable evidence of thinking. In this way, mastering the logical structure of language becomes a way to learn how to reason and a highway to abstract thinking (Barth 1987).

Language is Theory and Action

Language as theory in science and in science education is considered to be a specialized system of interpretation: it is an active modeler of experience (Sutton 1998). Language is also a tool that supports reasoning, but the patterns of language influence the patterns of reasoning about the natural world. Knowing science is talking science, so learning science implies developing new ways of talking and writing (Lemke 1993). Using language implies using a viewpoint to see the world in a different way. The system of language poses constraints to knowing and learning, and therefore orients students' cognition when modeling the natural world. Viewing language in this way has played an important role in understanding models and modeling in science classrooms, since it has forced researchers to situate language at the center of teaching and learning. In addition, it has also highlighted those problems faced in the science classrooms that are related to the relationship between the everyday language and the theoretical language used to interpret phenomena (Viennot 2007).

Viewing language as a mode of action in science classrooms implies giving students a voice, enabling them to use language not only to capture the truth but also to build personal and shared systems for interpreting natural phenomena. By using language in this way, students develop linguistic cognitive abilities that help them build models from their experience. These linguistic cognitive abilities constitute forms of action that were first referred to as language games by Wittgenstein (1997/53) from his philosophical position toward language. The metaphor of language as theory and action supports a view of language that is challenging. Science education researchers need to see language as a mutually reflexive relationship in which modeling shapes language as much as language shapes models and modeling.

Language is Interaction

This view of language is based on the idea that language exists in interrelation with the social context, social activity, or community of practice. Language is thus an interactive phenomenon that is socially situated. This view of language stresses the dynamic nature of language, its diversity of uses, its tight relationship with the conditions of its production, and its changeable nature through time and space. The concept of context in language-production activities becomes fundamental and the way to understand context determines the research tradition (Duranti and Goodwin 2000). Context can be seen in various different ways having different epistemological, ontological, and methodological implications: as a set of variables, as an external audience, as a community of practice, or as a social activity. Carlsen's third view of language (Carlsen 2007) takes the notion of context as a community of practice and takes into consideration the influential work of Wenger (1998).

Language seen as interaction increases the expectations of science education research on models and modeling in important ways. For example, researchers include in the context for language production other aspects such as reality, experience, and experimental action. We would thus include new dimensions to the study of language that take into consideration not only how language interacts with cognition but also how language interacts with natural phenomena through learners' actions. Researchers also conceptualize science education activities, and more generally school science as authentic scientific activities with their own autonomy, deploying their own language, school-science models, and scientific modeling practices.

Research Perspectives on Models, Modeling, and Language in Science Education

The literature review included in this chapter shows a diversity of views on the meaning of the concept of model, its relationship to language, and the consequences for science education. We believe that the evolution of previous views on both language and models in science could provide a useful framework to organize these contributions.

The work on models and modeling in science education research literature is both broad and widespread around the world. The diversity of views and uses of the concept of model is also broad, and is in many senses confusing. Are models cognitive tools that students use to think about the world (model as a cognitive construct)? Are they scientific tools scientists use to build scientific knowledge (model as a scientific construct)? And are models teaching tools to support science learning (models as a science-teaching construct)? All of these are models, but the research work reviewed here puts the emphasis on just one of the three. The chart in Fig. 89.1 suggests a possible system to map the central actors and processes relevant in the studies. The general aim of this chart is to show how the research contributions alongside a more interactive view of language can be helpful in building science classrooms that promote scientifically competent students.

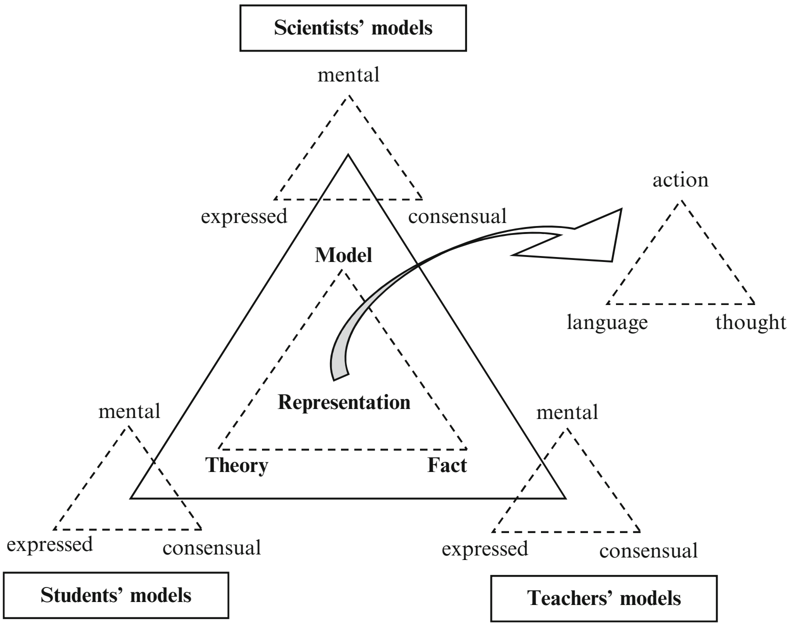

Fig. 89.1 Didactical system for modeling in science classrooms

Science teaching and learning constitutes a didactical system in which students, teachers, and scientific content interact in each activity undertaken in the classroom. We now describe the key elements of this system in a way that allows us to compare them in the research studies reviewed (Fig. 89.1). We consider that science teaching and learning constitutes an activity. When using a modeling approach to science teaching and learning, models can be seen as being held and produced by students, by scientists, or by the teacher. The aforementioned foci reflect the triadic nature of the science teaching and learning situations. Each actor in the science education activity system (students, teachers, and scientists) holds mental models. These models can be expressed, and can even be the result of consensus through social negotiation. Models can be cognitive entities, expressive entities, or entities built through interaction in social settings. A modeling approach to science education implies that the central content of the activity is the relationship between theory, model, and fact, that is, the relationship between the world of reality – made of objects, facts, and those phenomena – and the world of abstraction – made of theories and models. Models are thus representations that include actions, language, and thought.

The studies reviewed in this chapter have been organized into four groups in which there are similarities but also differences in relation to models and language: (a) research on mental models and language, (b) research on analogical models and language, (c) research on theoretical models and language, and (d) research related to recent developments in language.

Mental Models and Language in Science Education

Science education research using the construct of mental models is part of the cognitive-psychology research tradition that emerged from Johnson-Laird's seminal work entitled *Mental Models*, which was first published in 1983. The first science education research work on mental models began to appear in the early 1990s as exemplified by the investigations of Gutiérrez and Ogborn (1992). This work has continued until today, but the field has been developed very little. Since 1998, several research papers have been published on either students' or teachers' mental models. The research methods include paper-and-pencil questionnaires or clinical interviews through which verbal and/or pictorial protocols are obtained. Language is thus considered to be a means to the end of uncovering the content and nature of subjects' mental models.

There are strong similarities between the science education research on alternative conceptions that have broken into our field since the 1970s, and the research on mental models. The researchers appear to have substituted the construct of "concept" for that of "mental model." For instance, while Selley (2000) studies students' mental models of the particulate model of matter when explaining dissolution, Spiliotopoulou (2007) investigates students' mental models of the universe, and Shepardson et al. (2007) identify a typology of students' mental models of the environment. When researchers have investigated science teachers' mental models (Justi and Gilbert 2003), they have focused on teachers' ideas on models and modeling in science education as part of their pedagogical content knowledge (Henze et al. 2007).

Greca and Moreira (2000) have made a lasting theoretical contribution to the understanding of the importance of mental models for science education. For them mental models are analogical representations of knowledge composed by elements and relationships that represent a specific state of phenomena. Mental models are like cognitive construction pieces that can be combined and recombined. Mental models represent the object or phenomena and their structure captures aspects of the situation being represented. The function of mental models is to allow the science learner to make predictions about the real world: "Mental models are internal representations of information that have an analogical correspondence with the phenomena to be represented … Mental models are thus structural analogs of the world" (Moreira 2001, p. 195).

Moreira (2001) distinguishes between mental and conceptual models. Whereas the former are internal, the latter are public, external, and can be materialized in different symbolic forms. However, the relationship between conceptual models constructed by scientists, science educators, or science teachers and mental models constructed by students is not clear. According to Greca and Moreira (2000), students do not build copies of conceptual models; instead they build their own mental models, which act as intermediate cognitive constructs.

Modeling, then, is understood as the process by which students isolate characteristics of phenomena through a "modeling game" (Greca and Moreira 2000). The content of mental models built by students is restricted to the phenomena to which the model is analogous. According to Johnson-Laird's theory the content of mental models is restricted to conceptual primitives, which give rise to a finite number of semantic fields of human beings, which in turn give rise to a finite number of semantic operators. Both the semantic fields and the semantic operators impose limitations on the content of possible mental models. The language used for modeling puts restrictions on the possible mental models built by students. Modeling games allow students to develop their mental models and bring them closer and closer to the consensual model in the classroom (Clement 1983). The language used in these linguistic modeling games is close to the learners' everyday language. Language thus plays a fundamental role in building students' mental models.

We hope that research on mental models does not develop in the same way that research on alternative conceptions did. The field is not ready to accept another taxonomization of mental models like the taxonomization of alternative conceptions that took place. In addition, the lack of research on teachers' mental models indicates that the science education community does not consider teachers as modelers but as facilitators of students' modeling. This is a weakness in the field that must be confronted. Finally, in order to enrich the field of mental models, it is necessary to address explicitly the role of language in developing students' and teachers' mental models.

Analogical Models and Language in Science Education

Science education research dealing with analogical models and modeling is alive and well defined. This research departs from the objective of rendering scientific models and modeling more accessible to students. Analogies and analogical thinking have played a very important role in the history of science and they have been productive linguistic and reasoning tools for scientific thinking (Silva 2007). These literary resources taken from literature and linguistics proved to be powerful resources that enriched both the language of science and everyday language.

Researchers working on analogical models and modeling in science education share the idea that models are simplified representations of the complexity of natural objects and phenomena. They are cognitive tools that facilitate mental manipulation to build explanations of natural phenomena (Gilbert and Boutler 1998). Models are thus conceived as intermediate entities between scientific theory and the world of experience that can be taught and learned in schools. However, students hold mental models to explain natural phenomena that are represented in terms of everyday language and very often show difficulties in using scientific models. Analogical models are teaching tools designed to help students build mental models that are closer to the consensual scientific models. However, we would like to point out some differences shown within the research studies reviewed here that deal with the conception of analogical models. These studies understand analogical models as teaching tools, mental models, and science-teaching models.

Harrison and Treagust (2000) consider analogical models as representational teaching devices used in the classroom to facilitate the visualization of a scientific model. They include all kinds of more or less abstract representations supported by a variety of communicative modes. For these authors, modeling is an activity controlled by the teacher in which students engage in establishing correspondences between the analogical model and the scientific model, the latter being the target model. Analogical models are therefore simplified representations of scientific models, and modeling is interpreted as a conscious process of comparison between two types of representations supported by two different language systems.

Oliva et al. (2003) provide a framework to include analogical models in students' learning processes. The authors depart from the work on mental models and include analogical models as a new category of students' mental models. As in the previous study, analogical modeling implies an activity of establishing correspondences between two models: the analog and the scientific. The commonalities between these two models constitute the analogical model. Unless students can build analogical models through the correspondence activity, they will not engage in successful understanding. Thus, analogical models are mental models and analogical modeling is interpreted as the process of building a second-order model out of a comparison between models coming from two different domains.

Finally, a third group of science education researchers considers analogical models as authentic school-science models that are different from the scientific models. Hart (2007) expresses her profound discontent with the scientific models used in the classroom to teach electric circuits and suggests that science educators and teachers take the liberty to select better analogical models to promote students' learning. These analogical models would be chosen based on different standards that would depart from the traditional epistemological scientific standards established by the scientific community. In her research she studies how teachers build alternative analogical models to understand electric circuits and how they evaluate their potential for science learning.

Galagovsky and Adúriz-Bravo (2001) provide an example on the dynamics of cell membranes from this perspective on analogical modeling. In the first of three phases, a group of students is asked to think of a house as a place that internal and external agents enter and leave. The students are given a list of agents (air, a piano, mosquitoes, smoke, a letter, a doctor, etc.) and a set of questions applying to those agents: How does this agent enter or leave the house? Does the agent move by its own means? What actions does the agent develop to enter and leave the house? Is anything helping the agent? By answering these questions, students build an initial consensual analogical model of a cell membrane based on the familiar phenomena of a house. The students use their own everyday language to build an initial representation of the most important features of house dynamics. In the second phase, the students are asked to establish correspondences between the consensual analogical model previously established and the fundamental aspects of the dynamics of a cell membrane through the reading of scientific texts. Finally, in the third phase a metacognitive activity is proposed to the students in which they evaluate the correspondences of the analogical model that they have just built.

Despite the fact that analogies are in essence important linguistic and literary resources that frame understanding, little explicit emphasis has been placed on language by research on analogical modeling in science education. The implicit view of language in this line of research is that of a medium facilitating the disclosing of mental models. However, the weight given to symbolic representations in analogical modeling provides a very rich context in which to explore the multimodal nature of language in shaping students' understandings of natural phenomena.

Theoretical Models and Language in Science Education

The science education research on models and modeling, included in this section, come from three different science education research groups that hold explicit views on language and science. The research questions posed by these studies directly address the problem of language, which was not a central issue in previous reviewed studies. The first of the three research groups recognizes the influence of a sociocultural view on language and highlights the role of dialogicality in modeling (Leach and Scott 2003). The second group acknowledges the influence of an epistemological view referred to as new empiricism and highlights the importance of experimental action and language in models and modeling (Sensevy et al. 2008). Finally, the third group recognizes the influence of a cognitive view of science and develops the basis for a school science whose central aim is to develop theoretical school-science models (Gómez et al. 2007).

Despite the different influences, all the science education research studies included here recognize the crucial role of models in linking the perceptions of real phenomena with the theory. Language becomes a central element in the conceptualization of what models are. The studies also share the idea that a key issue of modeling in science education is the establishment of a constant, progressive relationship between the world of real systems and the world of abstract systems. Language also becomes a central element in modeling by making the connections between these two worlds possible. Finally, all the researchers share a commitment to produce science-teaching proposals that are coherent with their framework.

Modeling from Sociocultural Views of Language

Buty and Mortimer (2008) address the role of teachers in developing teaching sequences that deal with modeling processes on optics and dialogic communicative processes together. They stress the importance of teachers in building the conditions in the classroom to help students move back and forth between the world of real objects and phenomena and the world of models and theories. They take Bakhtin's view on language and incorporate the concept of social languages, thus distinguishing between everyday social language used in the science classroom and scientific social language. The authors acknowledge the importance for teachers to make a clear distinction between these two worlds and recognize that the way to relate the two worlds, changes depending on whether everyday social language or scientific social language is being used (Leach and Scott 2003). In addition, they are interested in describing the strategies used by the science teacher to build representations, and thus move from one semiotic register to another and from one speech genre to another. They assert that explicit modeling processes promote dialogicality and understanding in the science classroom.

Modeling from a New Empiricist View of Science

Sensevy et al. (2008) present case studies that provide evidence relating to models and modeling in physics and more specifically about mechanics. They put forward a proposal to teach modeling activities that is based on a coherent epistemological position. They take the legacy of the works stemming from the Stanford philosophical school and refer to their position as a new empiricism. From this epistemological view of modeling (Sensevy and Santini 2006), action, and thus the experimental dimension of science, takes on a renewed role. Model construction can no longer be seen as separate from experimentation and experimental knowledge. For the authors, modeling is an activity that establishes relationships between the world of objects and phenomena (experimental field) and the world of abstraction (the field of theory and models) when tackling problems.

Scientific models are the result of the dialectics between abstraction and concreteness, constituting specific realizations of this dialectical relationship. This view of a scientific model is certainly complex and challenging. In fact, the authors take the notion of the nomological machine from Cartwright (1999) to conceptualize what a scientific model is and how it functions in science classrooms. This nomological machine is understood as a set of game rules that allow identifying the regular behaviors represented in scientific laws.

Science classrooms are considered to be thought collectives where thought styles are developed. Through language games (Sensevy et al. 2008) and epistemic games (Santini 2007) students are able to move back and forth between the world of experimentation and the world of abstraction. These games take place through activities mediated by language through interaction in the classroom. For epistemic games, these activities include: describing, interpreting, predicting, defining, explaining, questioning, arguing, and critiquing (Santini 2007). Modeling in the science classroom is a slow, complex process that develops at different levels: it consists of different tasks determined by the language games or epistemic games (meso level), and it takes place through intense interactions (micro level).

Modeling from a Cognitive View of Science

Gómez et al. (2007) take a philosophical position on models and modeling that is based on the work of the cognitive view of science (Giere 1988). This view is used to support their conception of school science as an activity in which students and teachers engage in building theoretical models. These models generate ways to see and interpret the world and ways to communicate. Theoretical school models are not simplified copies of scientific models; rather, they are new, complex constructions that depend on the age of the students, the aims of science teaching, the social relevance of the natural phenomena to be explained, the nature of the scientific model, etc. It becomes fundamental that science educators working with the idea of this type of school science invest time and effort in selecting and building appropriate theoretical school models so that they become tools for science learning.

From there the authors undertake an interesting study in which, among other things, they develop the theoretical school model of the living being. They also design and implement a 5th grade primary-education teaching unit about fire in Mediterranean woodland. This unit aims to help students build a family of models that constitute the model of living beings at different organizational scales – the model of the cell, the model of the organism, and the model of the ecosystem – and also to establish meaningful relationships between these three model types. This research is thus a good example of the effort it takes for science educators to develop fruitful theoretical school models.

The work reviewed in this section has two implications for science education. First, the work points to the need to rethink the content of science teaching in terms of a few important school-science models. These models should cover how to act, talk, and think together. Second, the design of teaching sequences requires careful scrutiny in order to identify the best “facts” that have the potential to become “exemplars” from which to develop a process of abstraction that is characteristic of science learning.

Modeling and Language from the Analytical Traditions of Linguistics

The field of linguistics and communication is rich and has been influential in science education research for many years. Here we would like to briefly review science education research that has incorporated approaches coming from social semiotics such as rhetoric, multimodality, and narrativity related to the understanding of meaning-making in science classrooms. We also stress the value of such approaches for research on models and modeling in science education.

Multimodality

Social semiotics is another area that has mediated the practices of science education researchers interested in understanding the role of language in modeling the natural world. This line of research was originally influenced by the seminal work of Halliday (1978), and also the work of Lemke (1993) since it applies to science education. According to the social semiotics tradition, language becomes a multiple resource for meaning-making within social contexts that is displayed in different communicative modes for different purposes. This functional view of language was first extensively developed by Halliday (1985) before being applied to other communicative modes such as images and gestures in science education by Kress et al. (2001). The underlying assumption of this work is that different communicative modes contribute differently to meaning-making in the science classroom and thus have a different role in formulating models and modeling.

Márquez et al. (2006) studied classroom talk when modeling the water cycle in secondary-school science classrooms. They were interested in describing the teachers’ and students’ discursive strategies and the function of different communicative modes in building the model of the water cycle. Similarly, Buty and Mortimer (2008) use the concept of semiotic registers to describe the multimodality that characterizes science-classroom discourse. They identify four semiotic registers that are characteristic of science classrooms: natural language, mathematical symbolism, graphs, and diagrams. Their hypothesis is that the more the teacher promotes switching between these semiotic registers, the better students will engage in dialogic communication when modeling natural phenomena.

These studies highlight the idea that language use in the classroom is strategic and uses communicative modalities for different purposes in building school-science models. In addition, they suggest that models could be considered semiotic units in which all communicative modes act as resources for meaning-making.

In this sense we will take the dialectical meaning of concepts developed by Givry and Roth (2006) and state that models are also dialectical units of a semiotic nature constituted by different semiotic resources publicly available to teachers and students when making sense of natural phenomena. Meaning-making presupposes a language that is multimodal in order to develop an imaginative but constrained understanding that makes it possible to talk about one thing in terms of another (Roth and Lawless 2002).

Rhetoric

Rhetoric is a framework that has guided several interesting research projects on science-teacher explanations and science-textbook analysis (Martins 2001). Rhetoric involves organizing and presenting ideas in a coherent, cohesive, complete way, using communication resources so that students learn to see the world in terms of new entities. Rhetoric has a long tradition in philosophy, psychology, and linguistics. This is a new dimension of language through which school-science models are presented to students.

One side of this research concentrates on the study of the rhetorical aspects of science teachers' interventions. Sutton (1996) suggests that part of the job of science teachers is to persuade students about the value and reasonableness of the scientific views expressed in scientific conversations. Similarly, Ogborn et al. (1996) have focused on the way high school teachers construct and present explanations in the classroom and describe the different strategies used to create the theoretical entities that constitute scientific explanations of phenomena. Another side of this research has focused on the rhetorical aspects of science textbooks. Izquierdo et al. (2008) have identified the rhetorical characteristics of science textbooks and have related them to their narrative structure.

Narrativity

There is widespread use of narrative in scientific communication as a way to make science more relevant for the general audience. The role of narrative in promoting scientific modeling in science classrooms, however, was made prominent by the work of Ogborn et al. (1996). Scientific explanations could be considered narratives or stories, thus blurring the distinction between the paradigmatic-cognition characteristics of science and the narrative-cognition characteristics of social contexts in which action is relevant. Gilbert and Boutler (1998), in their chapter on models and modeling in science education, also recognized the importance of narrative in modeling. Narratives were considered to be text-supported representations that students and teachers construct to give shape to a teaching model or to a student's mental model. Sutton (1998) also introduces the example of stories as a way to bring out the voices of students, teachers, and scientists regarding these textual genres, and also to close the divide between facts and theories.

Sensevy et al. (2008), who take seriously the relationship between the concrete and the abstract in science education, have the courage to relate scientific laws and models with the analogy of the moral and the fable. In doing so, once again they identify narrative as a textual genre that has the potential to facilitate the transition between the world of phenomena and the world of abstraction, a transition that is characteristic of scientific modeling. However, much work needs to be done to obtain a clearer picture of the advantages and disadvantages of narrativity in modeling natural phenomena. The debate is still open, as is reflected in Orange-Ravachol and Triquet's (2007) recent review on narrative in science education, and the promises need to be fulfilled.

Consolidating a Model-Based View of Science Education

The reflections included in this review show the changes affecting science education as a consequence of changes in the view of science from knowledge to a human activity. These changes have been slow and have been influenced not only by the cognitive sciences, which highlight science as a product of human scientists, but also by the sociology of science, which highlights science as the product of the scientific community. This change also applies to school science and opens new possibilities to overcome students' difficulties in learning science when more traditional approaches are used, and to promote more meaningful learning. As part of this process, models, modeling, and language are key elements of an authentic school science that could be referred to as a "*model-based view of science education*."

Several science education researchers have recently made an effort to develop the characteristics and processes of a model-based view of science education that is epistemologically and pedagogically valid (Izquierdo et al. 1999). A model-based view of science education considers school science and science in general as two aspects of the same complex scientific activity. School science is thus a scientific activity that has some aspects in common with expert science but also some differences. Both, science in general and school science are philosophically founded within a cognitive view of science and a semantic view of theories (Izquierdo-Aymerich and Adúriz-Bravo 2003).

One basic characteristic of the model-based view of science education is that the content to be learned consists of a few basic theoretical school-science models that have a parallelism with the scientific models but that are not simplified versions of them. This work needs to be done by science educators, as exemplified by the work of Develaki (2007), who develops such models for classical mechanics, and in that of Gómez et al. (2007), who do the same for living beings. More recently, other researchers have been trying to build theoretical school models that introduce a contemporary scientific shift toward complexity and openness to other disciplines (Fourez 2002). These complex school-science models constitute a tool for science education to confront the challenges of the world's sustainability (Izquierdo et al. 2004).

Another basic characteristic of a model-based view of science education is its autonomy and openness to the entire community of learners. Any school science develops its own language, tools, and representations to best facilitate students' learning and, therefore, model-building. Learning science implies learning to use the language of science in schools through all its dimensions: as a channel for thinking, as an action to transform ideas, as interaction with others to explain or to convince. The semiotic view of language becomes especially relevant given the new communicative context shaped by new technologies in schools and society.

The teacher becomes a mediator within a model-based view of science education. Model-based teaching has already been investigated by several authors, although more work needs to be done to get a richer picture of its potential. Thus Halloun (2007) proposes a five-phase teaching frame for model-building in the classroom. He develops modeling schemata to assist teachers in helping students build models in the classroom. This modeling schemata provides teachers with well-defined dimensions and rules of engagement in modeling.

Summing up, the model-based view of science education represents an apparently subtle change in the way we understand science teaching and learning. Science education has advanced throughout its development as it has opened up to other disciplines. A model-based view of science education aims to be a model for explaining science education that takes into account the contributions of philosophy of science. We certainly believe that this model can be refined or improved by opening up to the sciences of language. The ideas developed in this chapter represent the first attempt to do so.

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Chapter 90
Teaching Science Reading Comprehension: A Realistic, Research-Based Approach

William G. Holliday and Stephen D. Cain

Reading in Science

Good science teaching helps students to understand science concepts and ideas and to begin to think like scientists think. The roles of scientist as experimenter and discoverer are well known and have been emphasised in many inquiry-based curricula and books. Equally important, but often not stressed, the roles of reader and writer are critical to developing science knowledge, skill and expertise. Scientists who report reading a lot tend to be higher achievers and more often recipients of professional awards.

Teaching reading comprehension to science classes means teaching to students, who can already read, a few reading comprehension strategies. We use the term *reading* here narrowly as students' ability to pronounce a text's words or, put technically, decoding text. The term *comprehending* is used to mean students' abilities to make inferences and/or to transfer rational meanings gleaned from reading a text to new contexts or settings.

We are specifically interested in science textbooks and other challenging texts, because success in reading these typically increases students' chances of academic success and, later, scientific productivity, according to evidenced-based research. Such science-comprehension teaching, theoretically, is best undertaken by experienced, informed science teachers during science class, and not by language arts teachers unfamiliar with science. A realistic, research-based approach means providing practising science teachers with practical guidelines based in research rather

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than impractical, idealistic teaching models that are unlikely to produce results in students within the context of everyday science classroom settings at educational levels ranging from upper elementary school to college. Research supporting our claims presented in this chapter is referenced in four scholarly documents authored by William Holliday (2004, 2005), Tamara Jetton and Janice Dole (2004), Michael Pressley (2006) and RAND Reading Study Group (2004) which are easily accessible, except where noted.

Warning: Popular Strategies Are Ineffective

Research-based guidelines make clear that many popular reading comprehension strategies are ineffective. These popular strategies include: (a) the pre-1900s round-robin reading method in which students take turns reading out loud; (b) appealing conglomerates of reading strategies such as the ‘SQ3R’ method in 1946, which involves students surveying, questioning, reading, reciting and reviewing; and (c) application of the unsubstantiated Bloom’s taxonomy in 1956 that describes a yet-to-be-validated hierarchy (except the knowledge and comprehension levels) and makes no research-based sense.

The problems with these approaches are many. For instance, during round-robin reading, student readers spend energy trying to look good in front of classmates; other students are often neither cognitively attending to the activity nor learning about the topic being read. A problem with empirically assessed conglomerates such as SQ3R is that, in controlled experiments, conglomerate treatment groups systematically fail to outperform control groups. Bloom’s taxonomy sounds like a good idea, except for the lack of supportive evidence-based theory and research, as noted by Richard C. Anderson (1972). More generally, it is amazing how long myths can stay alive, resulting in pre-service teachers in universities being taught and tested about, for example, Bloom’s six dreamed-up levels and their mythical hierarchy.

Nevertheless, if these three notions seem to work for you, then perhaps you should not categorically dismiss them. Still, we encourage science educators to consider research-based approaches as we describe in this chapter. Our focus is a topic not often discussed in science education: reading. We argue that it should be front and centre.

Obstacles to Teaching Reading in Science

This chapter is intended for science educators on the front lines of education, whether serving as teachers in the classroom, curriculum developers or science curriculum administrators. Because we know that most teachers do not have an in-house reading specialist or a team of specialists specifically dedicated to each science teacher’s efforts, we hope that we are as practical as possible.

Before we get into specifics, we acknowledge that it might be difficult for science teachers to devote instructional time to anything other than science topics. We have heard from many practising teachers the reasons why they do not teach reading comprehension strategies. They have told us that (a) they need to use class time for teaching large amounts of science content in order to prepare students for year-end, high-stakes, standards-based examinations; (b) they must devote more time to hands-on, inquiry-oriented activities; (c) they excel in explaining and clarifying the meanings of science concepts and were not trained to teach reading strategies; (d) they are concerned that teaching reading comprehension strategies might not be received well by students and thus could result in undesirable classroom management problems; and (e) they are familiar with trusted sources such as the *National Science Education Standards* (National Research Council 1996) and recent nationally based works, such as *Taking science to school: Learning and teaching science in grades K–8* (National Resource Council 2007) *and Ready, Set, Science*! (Michaels et al. 2008), and note correctly that these do not give practical guidance for teaching how to read and comprehend the information presented in science texts and other reading materials.

Nevertheless, or perhaps in spite of these conditions, we believe that teachers and students will reap significant learning benefits from more attention to reading comprehension strategies. Time invested early and consistently in a school year can lead to improved students' skills so that they learn more and perform better throughout the year.

Science books are examples of what reading educators refer to as 'informational text', the technical term used to describe text that communicates knowledge and is distinguished from text containing stories, which is called 'narrative text'. For too many years, students have learned to read informational text in disorganised trial-and-error methods (Jetton and Dole 2004). It is well established that many students need stronger 'skills' in reading informational text in order to achieve in elementary and secondary school as well as in college and in the workplace. It is time to excite national science education leaders as well as teachers to implement what we know about how to teach reading comprehension strategies in science classrooms.

Good fundamental reading instruction is no doubt taking place in elementary grades, as shown by national tests and reports such as the recent Nation's Report Card. Yet there continues to be evidence that nearly half of US high-school graduates are not ready to read college-level textbooks (i.e. mostly informational texts) by the time when they complete secondary school. Reading skills are critical for academic success at all educational levels, but especially so in college where professors expect students to read extensively. Published and anecdotal reports suggest that many college students do not read as much as their professors expect (Bonner and Holliday 2006). As a famous book title suggests, the world has become flat, meaning that people anywhere can now interact and exchange information via technology almost as if they were physically in the same place. This worldwide communication revolution is full of informational text that needs to be understood and remembered.

Putting Research to Work in Your Classroom

What, then, is a science teacher to do? If the class consists entirely of excellent readers, consider yourself fortunate and take them on an exciting science learning journey. On the other hand, if students are not learning from science text and reading materials, then read on. In this section, we first briefly describe some research-based guidelines for teaching science reading comprehension. In subsequent sections, we provide a more detailed description of approaches linked to students' prior knowledge, their motivation and the methods of teacher modelling. Keep in mind that the ultimate goal of teaching science reading strategies is for students to be competent, independent, self-reliant readers.

Research-Based Guidelines for Teachers

Pick a Reading Comprehension Strategy

Identify one of a few reading comprehension strategies that initially seem applicable to your science texts and learning goals. Of course, students should have many reading comprehension strategies available to them as they read. We agree that science teachers have limited time to ameliorate problems of past inadequate strategy instruction. (And, remember, no one research-based strategy is generally better than the other, contrary to reading folklore.) No doubt, you have heard of many strategies, and we list them here as a reminder of those from which you can choose: mapping concepts; generating graphic organisers; summarising text sections; questioning text meanings; producing mental images; using targeted strategies that link students' prior knowledge with text information; hypothesising or predicting what the next text section will explain; clarifying fuzzy text; making inferences based on text already read; discussing reading purpose before reading; reorganising a text; comparing and contrasting differences among described concepts; identifying the gist of a text section; paraphrasing portions of texts; identifying and describing main ideas; monitoring reading understanding; pausing to reflect back on text sections; staying alert; planning for productive reading time; using mnemonic devices; and using rereading (also termed 'look-backs' by teachers who work with younger readers) when comprehension fails. Do not listen to people who encourage teaching lots of reading strategies at once or during a short amount of class time because the research suggests that such approaches ordinarily fail. Teaching even a single strategy takes a great deal of class time. Individual science teachers are the only educators who know best the attributes and limitations of their students and the class setting, and which strategies should be emphasised. Each teacher must exercise professional judgement.

Plan and Practice Before Teaching a Strategy – Don't Wing It

Practice and refine your teaching strategy by experimenting with an approach (see the example described below) before teaching real students. If your first choice of strategies fails to make sense after a short tryout in a simulated context of your class, select another strategy. Teaching comprehension strategies will be effortful, or even stressful and unrewarding at the beginning of such a project. Consider piloting your approach with a small group of students first. Science reading comprehension lessons should be undertaken using the text ordinarily read by your students, not a contrived or reconstructed text, which is an attractive idea but lacks practicality in practice, according to a 2004 RAND report. Teach using very short passages at the beginning. Devote a realistic amount of time, say 30 min, every fourth class period (our arbitrary time recommendation, not assessed by research). Like physical exercising, expending extraordinary time and energy using unrealistic, sky-high learning goals most often results in abandonment. Because successful strategy instruction typically moves slowly, taking many weeks, pace yourself to avoid teacher or student burnout.

Explain Each Selected Reading Strategy

Research consistently suggests that hoping that students will 'naturally discover' how to comprehend informational texts is a sure-fire way, at best, of delaying students' abilities to extract meaning (i.e. comprehension) from science texts. The unsystematic trial-and-error methods of the past, with their unguided, independent and inefficient inquiry, forced students to rely on fend-for-yourself approaches. According to the research, such approaches are most harmful to less-academic students. The notion that students will learn such a skill by 'reading, reading, reading, and reading' represents a principle counter to the research-based evidence and is seldom believed valid by reading educators who regularly follow the research-based literature. No one is against students engaging in reading lots of informational text to develop comprehension fluency, but we need to teach students how to comprehend just as we need to teach children how to swim beyond 5 m. True, some children will learn how to swim 50 m without instruction. And some students will learn to comprehend science text on their own, but such outliers are too rare in a society dependent on scientifically literate people.

Model Strategies by Talking Aloud in Class

Explicitly explaining a strategy must be integrated with teachers modelling. Specifically, teachers doing so describe and illustrate in front of a class how they apply a selected strategy when reading a short passage of science text. In other words, teachers need to read several sentences from a text, then stop and explain how they are applying the strategy to the partial passage. Following this approach increases the chance that students will understand what the text author meant. Again, teachers must use their professional judgement regarding which passage to read, how long students can remain attentive, how frequently to teach strategies, what to say to the class, how to bolster students' prior knowledge before teaching a strategy, and how to motivate while maintaining reasonable classroom management. We discuss more about prior knowledge, motivation and teacher modelling later, because these processes can be intimidating.

This approach works, as suggested by many learning researchers, but is underutilised in inquiry-oriented science classrooms. Science teachers can plan and practise modelling using science texts familiar to their students, as researchers recommend. When planned, as we have suggested, strategy instruction can be mastered. We have observed this with active middle-school and high-school science teachers teaching at separate schools and found that experienced, practising science teachers catch on quickly, but also profit from practice. These teachers, at the time, were enrolled in a graduate course in science education at the University of Maryland. In their classrooms, students of these experienced teachers seemed to relish seeing and hearing their teachers struggle a little with science passages that their students found troublesome too. Observing 'struggling' teachers navigate text successfully could help students to understand that comprehension initially is an effortful task for everyone.

Describe When and Why to Use Strategies

Experimental evidence showed that students who were told when and why a strategy was applicable were more likely to learn the strategy compared with other students assigned to control groups. Students need to know that strategies such as concept mapping represent a potentially excellent way of learning relationships among concepts and the basic attributes of each concept, among other things. In contrast, concept mapping as typically applied might not be the best strategy for learning complex, interactive subtleties of concepts or for making visual, yet meaningful, the subtle characteristics of concrete objects such as varying kinds of rocks. Keep in mind that applying reading comprehension strategies can be stressful to some students. They need to be convinced that such efforts are worth their time and energy.

Give Students Practice Opportunities and Feedback

Provide students with opportunities to practise applying a strategy with 'reader-friendly' text initially and with heavy teacher supervision. Then reduce teacher supervision over time as students show signs of fluency, understanding and willingness to use a strategy. As students become increasingly competent, help them with more difficult texts, still without frustrating them. Unfortunately, there are no magic teaching formulas, expert scripts or cookie-cutter models that work. Again, teachers must use their own professional judgements and remain flexible with regards to dozens of classroom variables, including working at motivating students who are reluctant to cooperate. Obviously, some students will fail to cooperate, as is the case with almost any other approach to learning, especially where cognitive effort and fear of failing might linger. Providing adequate practice and individual feedback admittedly takes away from other science activities such as laboratories, lecturing-discussion sessions and extensive preparations for high-stakes examinations. But students who can apply just a few comprehension strategies to their texts are better equipped to learn much more science on their own.

Prior Knowledge and Motivation: Setting the Stage

Next, we detail some teaching qualities of effective reading comprehension: helping students retrieve and activate their prior knowledge; and motivating them. We also provide additional guidelines and examples of teacher modelling.

Start with What Students Already Know

Getting students to retrieve and activate relevant knowledge already stored in their brains – just that information that is essential to make sensible meaning out of a science text – represents the most basic aspect of helping students to comprehend text. Some less-fortunate students have little prior knowledge relevant to a text and, worse, they more frequently retrieve knowledge that is specifically *not* relevant, thus resulting in confused interpretations and a cognitive mess. Other students are more fortunate.

By activating their prior knowledge, students will generate hypotheses about what authors are trying to communicate. Teachers will sometimes need to invent ways of assisting students in generating these. Readers continually assess mini-hypotheses or predictive guesses about text meanings as they read, and then dismiss some hypotheses and predictions while tentatively accepting others. This is one reasonable way of viewing a productive inquiry as students discover subtleties on their own often using a systematic, interactive ebb-and-flow strategic thinking process between their prior knowledge and science text, thus resulting in text comprehension. In other words, this process is a cycle of reading, relating what is read to what the reader knows, followed by additional reading, and then continual reconsideration of hypotheses that predict what authors mean. On the other hand, using uninformed trial-and-error methods often leads to confusion rather than comprehension.

Teachers should plan for the prior knowledge students should have before assigning a challenging text and be mindful to common misconceptions. For example, consider middle-school or high-school students who are reading a description of blood flow through a mammalian heart. A student who visualises the human heart as an object that resembles the shape of a Valentine's Day box of chocolates represents a student in cognitive trouble. Let us explore this situation more in depth. What is in the text? A science text describes the blood flowing through cardiac chambers, in and out of arteries, capillaries and veins, and returning from millions of alveoli back to the heart for pumping. Students with the Valentine's Day heart shape as their prior knowledge in this example are at a distinct disadvantage. Teaching the dual-pumping action of the mammalian heart represents a difficult yet important idea to learn. Teachers must continually ask themselves how they can help students to retrieve and activate what they already know that is linked to the text. If the answer is nothing, then teachers should give up immediately. But the answer is never 'nothing'. In practice, students always know something. No one's brain is a blank slate.

Consider this approach: Use a simplified visual of a heart to activate prior knowledge possessed by more-fortunate students while providing some of the same knowledge to less-fortunate students. In the end, the more fortunate students will naturally learn more from the demonstration and the assigned text. Nevertheless, consider demonstrating heart functions using a simplified schematic diagram of a heart by drawing a two-by-two table visual with the bottom two rectangles being larger than the top two. Such a barebones visual can help illustrate the size differences and relative location among the heart chambers, including the auricles and ventricles. Teachers could show their class cardiac blood flow at first without mentioning technical terms. Then, repeat the demonstration introducing the terms, clearly pronouncing them and using the same schematic visual. Pronouncing unfamiliar scientific terms located in a to-be-read text is important because students who cannot pronounce (i.e. decode) words cannot truly comprehend text containing those words.

Following this step, provide additional information using a more realistic, detailed diagram perhaps followed by a physical model of the heart. After a teacher makes such a 'heart' pre-reading presentation, students theoretically are in a better position to comprehend a challenging textual description of its basic anatomy and physiology. Students now have improved or enhanced background knowledge, with more-fortunate students ready to learn with greater ease and less-fortunate students in a better position to learn more information because their background knowledge, theoretically, was enhanced to varying degrees by the teacher pre-reading activity.

Motivation Is Key

Motivating students to comprehend science text is easy with some students and difficult to impossible with others. If students are not motivated, they are not going to comprehend. Recent research points to aspects of achievement and motivation as more important than previously thought, which is no surprise to experienced science teachers! Keeping students motivated to read and comprehend their texts can represent challenges for busy science teachers.

Motivating students to learn how to comprehend requires that teachers understand what motivates their students. These reasons are as varied as the number of students in a class and probably include a range of influences. Positive motivational factors include curiosity, enjoyment of a challenge, social involvement and recognition for academic achievement. Other equally powerful motivational influences, which might be stressful when taken to extremes, also operate in students and include a singular focus on earning good grades, the wish to outperform one's peers, or the desire to match the expectations of other people.

Following are six general guidelines from 'achievement-motivation' research literature that are likely to help teachers in prompting students to comprehend science texts, as suggested by the empirical data. We include them all here because of their importance for understanding students. Whether these prompts always work is another matter.

Avoid Creating a Competitive Environment

Make sure that students compare their comprehension performances with their own previous performances, instead of with their classmates' performances. Competition can be a powerful incentive for some students, but it can also discourage other students. Remind yourself not to announce students' grades, average test scores or names of students who score high on tests where reading comprehension was important.

Native Intelligence Probably Isn't the Issue

Discourage students from believing that the reason for poor text comprehension is native intelligence that was predetermined at birth. Learning obstacles experienced by the vast majority of students owe much more to insufficient prior knowledge and inadequate reading skills than to intrinsic disadvantages in student native capabilities. Malcolm Gladwell makes this point in his recent best-selling book *Outliers: The Story of Success*. Very few students (reportedly fewer than 5%) suffer from reading dyslexia, contrary to public opinion. Too often, students' failures are automatically credited to students' native learning capacities.

Learning to read and comprehend is strongly linked to motivation, enjoyable learning experiences and persistence in solving challenging problems, rather than to brain size and theoretical cranial configurations. In addition, avoid myths such as 'multiple intelligences' (Waterhouse 2006) and 'learning styles' linked to sensory modalities (Kratzig and Arbuthnott 2006), which are popular and offer seemingly academic explanations by some educators as to why students have reading comprehension problems, among other attributes. Katherine Kratzig and Gregory Arbuthnott (2006) recommend that educators focus on evidence-based theories such as those involving meta-cognition (i.e. the way in which students think about learning and strategies) and other constructs of self-regulation (i.e. linked to producing independent, self-reliant learners) to make meaning out of science text.

Use Collaborations to Make Reading Assignments Enjoyable

Some students work better when working with others by capitalising on each other's strengths. Other students enjoy working alone. All students must develop abilities to learn in both study settings. A recent assessment of middle-schools' and high-schools' reading programs revealed that cooperative learning experiences were helpful and produced modest academic results.

Instruct Students to Monitor Themselves

It is so easy to divert attention from school work to non-essential activities at school and at home. Do not let students fool themselves into believing that adapting to a low standard of comprehension is acceptable.

Reassure Students Not to Become Discouraged If a Reading Assignment Seems Difficult

All of us have trouble with comprehending science texts on occasion but, if we work hard by not giving up on challenging problems and concepts, we are usually able to complete most assignments. Some assignments just take a great deal more time and effort. Create an expectation that giving up without seeking help is not an option.

Tell Students to Reward Themselves upon Completing Their Assignments

We all enjoy rewards at the end of an effortful task. For students, such personal rewards could include recreational activities, playing games, browsing the Internet, watching television or being with their friends. Encourage students to post little signs in their work areas to remind them to complete reading tasks.

Modelling Reading Comprehension Strategies

Teacher modelling means presenting a description of the thinking that occurs inside a teacher's head as the teacher tackles a text while using a comprehension strategy. The idea behind the modelling is for students to listen and observe the model comprehending in order to get a sense of how they might think as they apply a strategy.

When teachers model comprehension strategies for their students, they demonstrate a potentially powerful cognitive processing and serve as an academic role model. Using students' comprehension fluency as a guide with a wide (not too wide yet not too narrow) variety of science texts to be comprehended represents a worthy academic goal. Motivated, skilled readers with extensive background knowledge might need little or no teacher modelling to succeed. However, less-experienced science readers are likely to benefit from such modelling. Based on input from practising science teachers, we believe that most classrooms contain students on all points of these spectra of prior knowledge/motivation/reading skill. This means that students need many opportunities to apply newly learned strategies to many examples of texts – as many opportunities as is reasonable. One problem with teaching ways of tackling challenging science texts and, more generally, problem-solving strategies is that transferring such complex knowledge to new learning situations or different classroom contexts can take huge amounts of time and can be difficult without help from an experienced, informed science teacher.

What should a teacher do and not do? There are no guaranteed-to-work approaches that demonstrate for students an approximation of how teachers wrestle with extracting meaning from text while concurrently talk aloud about their reading comprehension mental processing. One requirement, possibly counter-intuitive, is that teachers initially need to resist asking questions of their students and just provide an explicit demonstration of how a strategy is applied to a particular text, according to reading researchers. This will take some teacher effort because *not* asking questions is not a common way to teach. In addition, no two teachers are going to say the same thing during explicit modelling to a class. Teachers, keeping in mind an estimate of prior knowledge embedded in their students, must adjust what and how they model in an attempt to acquaint their students with how the teacher is managing to comprehend the target text. This requires teachers to talk aloud about their mental processing of text and linking strings of text words to what the teacher already knows. Such talks are sometimes referred to as 'think-alouds' or 'thinking out loud' in learning research literature.

Following are two examples of teacher modelling. The setting is a middle-school science class in which the teacher has planned a hands-on activity for the following day. In preparation, students have been assigned a chapter covering elementary organic chemistry. The first teacher, Mr Smith, chooses the approach of checking the structure of the textbook chapter.

First Example – Mr Smith

Mr Smith, announces the activity scheduled for tomorrow's class and assigns the chapter reading covering organic chemistry, and asks his sophisticated ninth-grade students to pay particular attention to the parts of the chapter relating to tomorrow's hands-on activity designed to determine chemical components of foods that students eat. Specifically, Mr Smith reminds the class to pay particular attention to passages in the chapter related to foods. Other parts of the organic chemistry chapter, according to Mr Smith, need not be read at this time.

He might talk patiently in a loud voice in front of his class making statements such as: 'For homework tonight, read chapter 20. Pay special attention to the sections about food'. 'You don't need to read the section about isomers'.

Second Example – Ms Jones

In contrast, here is an example of good modelling of how to begin to comprehend the same chapter by a teacher working under the same setting with similar students. This teacher is providing pre-reading knowledge about the assigned chapter. She might teach a strategy by reading several sentences and then stop and explicitly explain how she applied the strategy to a partial chapter passage (as described earlier in this chapter).

Ms Jones announces the activity scheduled for tomorrow's class and assigns the chapter reading. She then describes what she would do if she were a student. She navigates the chapter, talking aloud to the class as she charts her course of action. In other words, she pretends that she is a student assigned a difficult task and describes how she would attack the reading with the planned food activity in mind. She might talk patiently in a loud voice in front of her class making many statements such as:

> I need to pay attention to the meaning of the chapter title, The Chemistry of Food, presented at the beginning of the chapter.
>
> I need to read about amino acids, as they relate directly to foods, and read the major section covering biological compounds including sections on proteins, carbohydrates and lipids.
>
> I need to make sure that I understand the material directly tied to foods, question how the text can help me to prepare for tomorrow's activity, and then briefly summarise, in my own words, after reading.
>
> If I am foggy on important points, I've got to return to those sections of the chapter and reread them until I can make the connections between the information presented in this chapter and the activity on foods scheduled for tomorrow.

As Ms Jones models this reading, she might move page-by-page through the chapter with her students as she explains in detail what she would do if she were a student. She would seek feedback from students by asking them questions during this class and by assessing their compliance to her suggestions during the next class.

Conclusion

If science teachers take valuable class time to teach a few reading comprehension strategies, students will learn more science from texts, performance better on verbally loaded examinations, and probably outperform less-frequent learners in future science courses and in understanding science later in life.

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Chapter 91
Building Common Language, Experiences, and Learning Spaces with Lower-Track Science Students

Randy K. Yerrick, Anna M. Liuzzo, and Janina Brutt-Griffler

The publication of this volume follows decades of science education reform which has transpired through curriculum writing and alignment efforts and, most recently, assessment-driven reform. Although much progress has been made in the field, as evidenced by the size and quality of contributions to this volume, one consistent element of school science culture that stands out is a lack of progress in equitable science education. This element is the perpetuation of a lower-track science culture in nearly every American school district – a peripheral and often lower-status venue for learning science for those students who are unwilling or unable to master the academic discourse promoted in more "advanced" science classes. What is more alarming is the continued overrepresentation of racial, linguistic, and ethnic minorities populating this microculture of school (McCarthy 1998). In a volume devoted to the accomplishments of science education research, it is appropriate and unique for this chapter to speak to the potential revisioning of lower-track science classrooms from an insider's perspective, as perhaps only intervention studies can.

Science, Tracking, and Underrepresented Science Students

Sifting and sorting students has been a primary function of American schools for many decades (Bowles and Gintis 1976) and as such lower-track science students have been a part of the landscape of science student demographics through many revisions of science reform. Science equity became central to the discussion of science

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reform as student placement within track levels became a vital consideration for the sociocultural identities of lower-track science classroom populations (Oakes 1990). A disproportionate number of underrepresented science students have historically been placed in lower-track classrooms and their discursive practices have become marginalized in school. Teachers, pressured by assessment-driven curriculum, willingly or unwillingly comply with institutional models for content coverage and discourse practices surrounding this model, which precludes options for slowing down the pace and engaging students in meaningful discourse which connect scientific vocabulary and nomenclature to students' culture or real-world experiences. Anyon (1997) and Oakes (1990) argued that homogeneous grouping of students plays a large role in identity development of underrepresented students, and in the case of science, such grouping convinces students that discourse associated with higher-level scientific reasoning is something reserved for *others.* The available standardized skills and content assessments in science typically represent knowledge as sterile, objective, and factual (Poole 1994) and serve at least two purposes: to convey implicit messages of knowledge and learning and to lend credence to privileging a certain kind of discourse to which only a few school members have access (Apple 1979). Once enrolled, lower-track science students become convinced that not all students can succeed and may count themselves out of future scientific endeavors.

In such a learning context little room is left for diversity in student voices. Beliefs about science and about students are implicitly conveyed through teaching practices, school counseling, and testing that define for students their "rightful position" and voice – or lack thereof. Bosacki argues:

> Adolescent[s] may feel "silenced" either due to a lack of knowledge of the emotion word or by the "other" who does not allow the child to speak. … This experience of strategic silence may be more personal in nature, and although the motivation to self-silence may be influenced by the interactions of others, the decision to remain silent remains at a more private level. (Bosacki 2005, p. 13)

Silence can be the result of cultural differences in the child's upbringing in comparison to differences in school conventions. As Bosacki further argues: "Children continue to refine their pragmatic skills and sociolinguistic conventions [school and] this development is affected by cultural differences" (2005, p. 11). Teachers in lower-track science classrooms typically promote a sterile, factual, rote, disaffected treatment of science knowledge which ultimately results in the silencing of student voices.

However, the process of marginalization of student voice is not unidirectional. Lower-track students in response typically separate themselves from the official schooling process by using specialized language, resisting school authority, wearing alternative styles of clothing, and disdaining formal school success (Page 1991). The typical lower-track social-group response is to develop a microculture that creates cultural space and independence within and against the dominant culture of the school (McLaren 1994). Members of this microculture do not buy into the dominant school culture, and marginalized students typically respond with resistance (Solomon 1992). Consequently, becoming a member of the microculture many times requires devaluing or completely rejecting the dominant social group of the school (Willis 1977) attitudes and value systems. Alienated youth do not acquire this membership overnight, nor do all students necessarily accept it as their first choice. Some students have been socialized for much of their school careers in a system in which students were implicitly and explicitly guided into low-achieving peer groups by students and school officials alike. The differences between these students' experiences and socialization mark an active process of defining one's identity amidst conflicting influences.

These antisocial behaviors, poor achievement, and pressures of assessment-driven reform drive lower-track science to concentrate on achieving only basic factual science information based upon retrieval, recitation, and regurgitation. These in turn keep students' voices and teacher uncertainty out of the equation with the insertion of some significant questions. Is this the best representation of real science? Is this all we think lower-track students are capable of doing? A factual treatment of knowledge has been widely criticized for decades as an inaccurate representation of the science discipline. Suffice to say, science educators on the whole do not currently subscribe to the representation of science as rote retention of facts. We instead explore how norms of discourse in lower-track science classrooms could promote a new kind of *talking space* and how that space could inform best practices used in lower-track classrooms to better engage students in science as well as a mechanism for promoting a socially just treatment of students with histories of failure.

Some popular responses to assessment-driven science curriculum and teaching reform imply teaching toward specific basic skills and scouring test scores for the slightest increase in test achievement for confirmation of the correct direction. While we agree that science achievement scores should improve, we suggest a different entrance point to approach the issues of teaching and learning with this diverse student population. We believe that simply aiming to improve basic scores masks the nature of why students are not engaging in lower-track science classrooms and that the nature of remedying the disconnect for students can be found in other features of *science as a discourse* (cf. Lemke 1990) that can be actively promoted by science teachers. Similarly, our view of science as a discourse carries multiple representations that might include "conventional" ways of presenting concepts as well as ways that science connects to students' experiences and the communities in which they reside. Framing science as multiple discourses provides a conceptual space for students, which enables teachers to hear and shape students' worlds and begin building upon their students' learning.

In the next section, we present and analyze three vignettes from lower-track science classrooms to underscore the following attributes of opening up multiple discourses of science: (a) the role of authentic questions that emerge in the classroom; (b) the shifting notions of authority and risk taking in the classroom, and (c) the role of struggle over the ownership of ideas. Our analysis of the vignettes is informed by a Bakhtinian notion of "third space"; such an approach to science education can open up conversations of what lower-track students can accomplish and how teachers may create welcoming environments for a wider interpretation of success in science.

The New Dynamics of the Classroom: Refocusing Teachers' Orientations to Science Learning

As we discuss below, Bakhtin's framework of dialogue and "third space" construction is indispensible to understand the learning environment of the science classroom. Our analysis suggests that students must be actively engaged in learning how to "socially construct" their understandings by listening and offering their interpretations of commonly known data. In the same way that scientists construct arguments, students must be engaged in the process of examining what counts as evidence, how knowledge claims get conceptualized, and how knowledge is treated as an evolving process (Lemke 1990). Duschl and Gitomer (1991) have argued that an important objective for classroom learning environments is the promotion of arguments and explanations. Lemke (1990) argued that theories, for example, are not generated in a vacuum or on the basis of pure rational thought within the scientific discipline while focusing on the daily grind of the oral and spontaneous nature of science, including the treatment of ideas. Viewing science as discourse aids a researcher to consider not only what ideas are discussed, but with whom and for what purpose. Students' arguments serve to better judge whether students are practicing science rather than using specific terminology or similar conclusions scientists have published. Such a critical perspective of the formation of arguments, theories, and the context in which they are developed, raises questions that such practices should be promoted as appropriate in American school contexts.

Posing Authentic Questions: A Look Inside a Lower-Track Science Classroom

To construct such interactions, Bakhtin argues that all speech and language are embedded in social contexts and, as such, require a speaker and a requisite listener to respond. This framework is often not the norm in a traditional monologic classroom setting. A monologic framework does not promote the construction of understanding Bakhtin is referring to. Bakhtin argued meaningful response was critical to dialogue – the most fundamental aspect in his philosophy. Through such dialogue two participants come together in a "third space," co-constructing a new understanding that is created by changing both participants. Bakhtin argued nothing has meaning without context and would likely have disagreed with notions of transmitting knowledge as it is not a dialogic process. To establish this third space in a science classroom, science must be dialogic and contextualized. Bakhtin argued that words have no meaning, but meaning is constructed through our utterances, which are not objective. All utterances have value; therefore, all voices should be heard. Yet this description rarely applies to learning contexts of typically marginalized science students; a school culture embedded with issues which transcend content delivery or retention. We argue that a Bakhtinian framework must be employed to explore how teachers of lower-track students may participate in the co-construction of scientific knowledge in ways that mutually enrich science spaces for both parties.

To make our point we employ excerpts of students in lower-track classrooms arguing the merits of an elliptic heliocentric solar system when applied to available data. Two student-generated models have been presented, one from a student name Chantelle, who is arguing what most students believe – that the earth's orbit is an elongated ellipse and the seasons are caused by the proximity of the earth to the sun. The other students are exploring how the circular model of its orbit accounts for more of the available data. Both solar system models generated by students have been placed on the front board and students have explored annual global weather patterns as sources of data to defend their choices. For example, some students found that the Northern and Southern hemispheres do not experience summer at the same time while others found that Brazil maintains a relatively hot temperature year round at the equator despite the fluctuations above and below the equator. The students freely discussed their opinions and engaged in voting for and against these models for each set of existing evidence. During the ensuing debate, students questioned one another and tried to make sense of scientific concepts. They disagreed freely with one another and offered explanations for their beliefs. The students sometimes swayed to view scientific concepts in a different way and they began to question and construct their own understanding with peer support. The dialogue the students engaged in can be framed in a Bakhtinan way in that students decided what they understood and what they did not. In this setting, the students decided which evidence would best fit the experimental format. They were encouraged to explore other ways to make sense of the science concepts. In the excerpt that follows, students also used their own voice to construct meaning; they used their own language instead of scientific language to make sense of what they had found.

Teacher: Curtis do you have a vote yet? Yes or no. You don't have a vote yet? You don't have to vote yet. Katie, do you have a vote? Marshawn do you have a vote yet? On this piece of evidence right here. Brazil. Do you have a vote yet?

Chantelle: Mr. Yerrick

Teacher: Just a minute Yes or no? [pointing to Marshawn] Do you have a vote?

Daquinda: I have a vote.

Teacher: [Still indicating Marshawn] Yes you do have a vote?

Marshawn: Oh, I don't know why

Teacher: You don't have to know why. You just have to know whether it's for or against this model. Is it a plus or a minus? That's all you've got to know.

Marshawn: Oh, minus.

Teacher: Ok, Marshawn says it a minus. This is the first vote I've heard minus. I need to hear it and then we'll go like this [points to students moving right to left across the room] Ok? Shhhh. Listen to Marshawn's vote and his reason.

Chantelle: He just said he didn't know why.
Teacher: He doesn't have to know why he just…
Students: Oh, Whoa!
Teacher: He just needs to explain why it does or doesn't favor. Listen. [Waits, but Marshawn doesn't respond] [Pointing to board] Brazil, hot in July. Brazil, hot in the fall, in October. Brazil, hot in January. Brazil, hot in May.

This teacher allowed the students to take the time to "assimilate" the words being spoken. The content of this excerpt revolved around student-generated ideas as the teacher encouraged all students to offer their opinions even without demanding the correct reason for their explanation. In this case, the teacher gave Marshawn additional time to respond. Marshawn was allowed to offer a vote without an explanation, but the teacher returned to him after giving him some time to formulate a justification. The wait time given to the students gave them the opportunity to make sense of the dialogue taking place. The time given allowed for the student to make sense of what was said. Bakhtin referred to "the self as a changing entity, engaged in a dialogue" (Hall et al. 2005, p. 180).

We assimilate others' words and add ourselves to make them our own. The words belong to us; it is our utterances that hold all of the meaning. Bakhtin believed meaning is constructed when an author and an active listener are present. Meaningful response is critical to dialogue. The new understanding and meaningful responses often take additional time to formulate. Marshawn struggles because he cannot offer evidence to back up his vote. The other students responded with "Oh, Whoa" when Marshawn is allowed to "slide" by without explanation, yet no one pursued it any more than that. In the following excerpt the teacher asked for additional votes and returned to Marshawn.

Stephani: I'm just not ready yet.
Teacher: BeeBee wants to vote and then Marshawn
Rocky: I want to vote
Teacher: Shh. Ok, just a minute. Rocky's gonna vote too. BeeBee first.
BeeBee: [Coughing]
Fatima: Pat his back
BeeBee: [Teacher approaches BeeBee, he raises his fist] Hey, hey, HEY!
Teacher: [Laughs, and raises his fist]
BeeBee: Naw, some ya'll get carried away. Um. [says something unintelligible]
Teacher: Ok, BeeBee thinks it's a minus, but you've got to tell us why. It's not just a vote, it's a reason.
BeeBee: Oh, god. Um, uh, just like that one.
Teacher: Nope, not a good reason.
BeeBee: Why?
Fatima: He said cause it bad…
He said plus.
BeeBee: Nah. It's a minus because you got [unintelligible]. It don't support the theory. It's that one.

Teacher:	Why? You gotta tell us why.
BeeBee:	I don't know why! I don't know.
Chantelle:	Mmm, ehhhh! [buzzer noise]
Teacher:	Ok. It doesn't count, but you can still think and listen. Marshawn and then Rocky.
Marshawn:	I think it's a minus on this one, because um,
Chantelle:	Ehhh!
Marshawn:	It with the circle it's at like a constant rate around the sun, and then with its tilt it's always, you know, at the same place.
Chantelle:	Booooo
Fatima:	Be quiet!
Teacher:	Chantelle! That's rude!
Marshawn:	I know, right.
	[several students talk at once]
	BeeBee: Smack her, smack her.
Chantelle:	I'll be quiet, I'll be quiet. Go ahead, go ahead.
Teacher:	Yes. Marshawn says minus.
Fatima:	It's tied.

Most notably, students refer to one model as "Chantelle's model," demonstrating ownership of the concept. Dialogue must include more than one voice and typically, the only voice that matters is that of the accepted science concept. However, in this context, the teacher acted as a facilitator, allowing the students to express their own ideas and offer explanations for their views. The fact that students are calling models by their peers' names and pursuing warrants based upon evidence, is strong support for what Bakhtin argued are meaningful responses critical to dialogue. If teachers are to be successful in reengaging science students with histories of failure certain shared social, emotional, and cultural connections must be established as mutual attributes of the science learning context.

Further evidence for the necessity of Bakhtin's "third space" is found in the utterances of students confirming and disagreeing with claims made regarding available data. In this context it is clear that all utterances have value and are heard. Chantelle tried to move her peers to agree with her by "buzzing" and "booing" their comments. She neglected to argue her point using data but instead tried to manipulate her peers in a light and humorous manner. The culture and relationships in this classroom were clearly illustrated in the ongoing banter between the students and teacher. Students spoke freely about circular and elliptical models they had generated and argued about evidence they had collected as they were actively involved in the social construction of meaning. Shared discourse was driven by artifacts and children's utterances as this teacher valued their contributions in newly constructed "third space." In the end, Chantelle conceded, stating that "I'll be quiet, I'll be quiet. Go ahead, go ahead." Although she eventually allowed her peers to finish their arguments, she never accepted the flaws in her design. She left with the same misconception she entered with.

Negotiating Authority and Risk: How Mutual Discomfort Signals Equal Risk and Investment

Such a social format is an uncommon occurrence in a lower-track classroom where antisocial behaviors are the norm. The teacher encouraged ongoing discourse through differences of opinion. This model stands in sharp contrast to the traditional approach taken in lower-track classrooms where teaching has often been relegated to a constrained delivery of facts under the pressure of accountability. Bakhtin has also argued that all voices must have a valid stake in moving the discourse forward. This is too often not the case when the teacher holds unequal power over students within the discourse setting. Consider the following excerpt, which contrasts with a monologic transmission which decontextualizes content knowledge and runs counter to what we understand about marginalized learners. Nearly every participant, including the teacher, shares discomfort in some aspect of this newly created discourse space. In fact, under these expectations students freely and willingly move into an uncomfortable space for the purpose of pursuing claims made about data. As in a scientific community where scientists have developed ways within their community of debating ideas, producing evidence, resolving conflicts of interpretation, and communicating their work, there must be recognizable differences in opinion for true dialogue to take place. Only then will there exist a space where differences in opinion are encouraged and necessary for dialogue to continue. This is often an uncomfortable space for all involved.

Teacher: Ok, so one person said minus for that model. Latiffa, what is your vote and tell me why?
Latiffa: Well, a plus on that model, I think.
Teacher: Ok, a plus on this model is a minus for this model. If it favors that one then it doesn't favor that one. Right?
Latiffa: Is that Chantelle's right there?
Teacher: This is Chantelle's.
Latiffa: I don't like Chantelle's. I like the other one.
Chantelle: I don't appreciate it.
Teacher: Well it's not about you, Chantelle.
Latiffa: I don't, I don't mean Chantelle the person I'm just talking about.
Teacher: It's not about you.
Latiffa: I don't … [Laughs] I don't, I don't go for her model.
Teacher: Ok. So we have two votes for a minus, minus.
Fatima: Ain't that a [unintelligible] it got the sun lookin like it's closest to Brazil.
Teacher: Yeah. It does look that way. It does look that way. I need three more people to tell me their vote. Marshawn didn't vote yet. Curtis couldn't vote yet. I need three more people to vote. Stephani, you want to vote?

Chantelle demonstrated her discomfort stating, "I don't appreciate it," defending her beliefs but not offering any real explanation for her idea. She interpreted difference in opinion as a personal vendetta, but she owned her ideas and remained distinct from her peers. Chantelle, Marshawn, and Latiffa's differences in opinion were necessary in order for authentic dialogue to continue. In the culture of this classroom, many teachers may be reluctant to give up the control needed to allow differences in opinion to take full form. The uncertainty of where the argument may lead is often a risk many teachers will not take. The importance of establishing a culture in the Bakhtinian sense of the word was a necessity for this to succeed.

Traditional teachers carrying out established, predetermined sets of skills and outcomes violate what Bakhtin promoted in the establishment of a new culture. He argued: "The dialogic encounter of two cultures does not result in merging and mixing. Each retains his own unity and open totality, but they are mutually enriched" (Bakhtin 1986, p. 159). Bakhtin advocated that speakers assimilate other's words and add ourselves to make them our own. The words belong to us; it is our utterances that hold all of the meaning. Through dialogue the two participants come together in a "third space," a new understanding created by changing both participants. Without the freedom of dialogue and disagreement, two participants are unable to come together in a "third space." Speech and language are social and therefore a speaker needs a listener to respond. If we continue to keep these students silenced, we hinder the development of their "self." "Language is the essential medium of dialogue and self-formation" (Hall et al. 2005, p. 155).

These excerpts underscore the importance of students questioning one another and trying to make sense of scientific concepts. Students *can* disagree with one another while offering explanations for their beliefs and students are sometimes swayed to view scientific concepts in a different way as they begin to question and construct their own understanding. Chantelle never let go of her initial claim or her own identity, as she was not moved to an alternative conception. Other students, however, appeared to transform their own ideas and change their conceptions. Although much has been written about the difficulty of changing specific misconceptions, this process of promoting learner-centered dialogue has moved at least some students publicly toward the correct answer. The results stand in stark contrast to the reasoning offered by students and teachers in the Annenberg study (Harvard-Smithsonian Center for Astrophysics 1997), which demonstrated traditional transmission modes of disseminating facts do not yield such outcomes. These students became involved in authentic dialogue and through one another's differences in ideas; they were able to negotiate a third space of understanding. The students were using their own voice and their own language to make sense of the concept. In The Problem of Speech Genres, Bakhtin states (1986, p. 63):

> After all, language enters life through concrete utterances (which manifest language) and life enters language through concrete utterances as well. The utterance is an exceptionally important node of problems.

In short, Bakhtin argued that one should then expect that different lives create different languages or discourse. This point by Bakhtin illustrated the undeniable importance of discourse in our lives and the need for social construction of understanding. This only takes form in dialogue. "Dialogue is not simply a verbal act of interaction; dialogue, is universal communication which is the basic principle not only of culture but also of individual human existence" (Hall et al. 2005, p. 155).

The students in this class assimilate others' words and add themselves to make them their own.

We can never be sure what we say is interpreted the way we meant, because we all come together with differences. Through an ongoing dialogue the best we can do to reach a third space in science is to provide opportunities where students can construct meaning for themselves. Is this third space one means for transcending the cultural borders present in our science classrooms and our lives? In this context this teacher felt the need to stop the silence and truly promote the dialogic atmosphere essential to learning. Consequently, the "third space" was a real student-created semiotic space and one that potentially aids science learning.

The Right to Claim Expertise: Newly Appropriated Norms, Student Ownership, and New Representations of Scientific Thinking

So far we have discussed how students' ideas become an integral part of the conversation about science by having students pursue their own ideas, openly claim the common-sense understandings, contrast them with others in the class, and seek evidence to accept or refute claims on the basis of evidence and argumentation. We have also demonstrated that shifts in teaching that result in these kinds of interaction require the construction of a third space – a space where neither party is entirely comfortable. In this discourse space, the teacher laid down part of his/her content area and language authority and encouraged students to lay down their antisocial tactics in pursuit of exploring the veracity of their own questions in authentic ways.

We now turn to the question of ownership and identity. The question remains, who gets to contribute to scientific knowledge, who owns it, and why? In a Bakhtinian third space for lower-track science, students and teachers, and even outsiders to the community have different identities and thus exert different claims toward ownership over the same ideas. The debate around the question of whose ideas get included in science has existed for as long as science has been a part of the content curriculum of school. Bakhtin postulated (1986, p. 158):

> Need to maintain one's own identity in order to be able to speak to and to understand others precisely because there are many voices and, therefore, a multiplicity of dialogues involved in an act of communication.

In the preceding examples, BeeBee, Marshawn, Chantelle, and Latiffa are all exploring a commonly held misconception regarding different models for explaining seasons. Chantelle's model can be clearly seen by the expert science reader as wrong for a variety of reasons. However, simply because the teacher can recognize the error in Chantelle's model does not establish in the minds of students any cognitive dissonance or need for further explanation, particularly ones who have been marginalized by school science discourse. Bakhtin argued that meaning is only constructed when there is an author and an active listener. Meaningful response by participants *other than the teacher in this context* is critical to maintaining an authentic dialogue. Through dialogue the two participants come together in a third space, a new understanding that was created by changing both participants. We do not use the term dialogue as simply verbal interaction. Dialogue as we use it here in this context represents a medium of cultural transmission of individual human experience and existence (Hall et al. 2005, p. 154). We see evidence of this dialogue through the challenges of Rocky to Chantelle's model, a popular and well-respected student in the class.

Teacher: Barbie and then Rocky. Did Barbie not get a turn? Ok. She just wants to say something and then you'll go. Ok, you were saying something that supports your model.

Barbie: Yeah, I chose that one because the temperature goes down at a different time of year.

Teacher: I understand, you at least offered some kind of reason and data behind your vote. Your thinking actually supports your model. Ok, Rocky. Rocky, I want to hear your vote.

Rocky: Um, I don't, I don't think…

Teacher: Shh. Rocky doesn't take the opportunity to very often and he doesn't speak real loud, so I want to hear him and I am sure you do, too.

Rocky: Um. Uh, Chantelle's model, how it. Can you see when it… When, when the Earth is Farther away from the sun…I don't see how it [Brazil] can still stay warm in Chantelle's model. [Referring to Marshawn' data]

Teacher: You are saying, Rocky that you don't see how Brazil can still stay warm, when it's far, far away from the sun. [Pointing to Chantelle's model]

Rocky: Yeah, I don't believe that can actually happen if that is the right reason.

Rocky, a rare contributor but astute listener has been taking in the debate for several days, working quietly in his group and taking his own quiet pulse of the argument. When Chantelle's model came under increasing scrutiny, Rocky feels compelled to support Marshawn, another quiet male voice. Although he gets off to an uncomfortable start, he appropriated Marshawn's critique of Chantelle's model and the student-generated data to cast doubt on the elliptical model of the solar system as the reason for seasons. He argued that Brazil could not maintain its warm year round temperatures that Marshawn found in the World Almanac, if the distance was the reason for annual temperatures. Throughout Chantelle's increasing intensity in her attempts to silence her opponents, Rocky, a routinely shy and quiet student recognized the multiplicity of dialogic interactions and the opportunity in this third space to offer his own interpretation of data. His identity was one that reflected a learner and a knower of science as he argues that he just "doesn't see how that can happen."

The argument ended after several days with all the evidence offered by students under the scaffolded group discussion by the teacher in a space where most teachers would likely be more comfortable getting right to the answer much more quickly and moving along. However, after all evidence was amassed on a "for" and "against" tally chart, the vote of evidence heavily favored the circular model of the solar system as a model to explain the phenomena of seasons. Of course, this begs the question of whether or not it would still have been an authentic example of Bakhtin's third space in this science classroom if Chantelle successfully defended the wrong model. We do believe and have further evidence to the fact that it *would be* but we leave this for future work to explicate.

The above vignettes offer strong evidence that students' identities toward science and toward school can be modified and could provide pathways for great student learning. But we want to press our argument further about lasting identities and the potential to interact with the world outside this isolated classroom community. The common thinking about science education diversity interventions suggest that if students *see* someone who looks like them succeed in science, that success will encourage more science interest and effort on the students' parts. However, interventions originating from this approach have met with minimal impact, particularly in urban settings. What explains this nominal contribution from such a common sense strategy? We believe the answer is found in the ownership of the scientific ideas. Having speakers talk about *their* work *at* students does not accomplish the kinds of conversations that we have exemplified via the three vignettes in this chapter; they demonstrate that students' identities can be impacted in the third space where identities of students can change. This kind of shift in identity often happens at junction points where students' ownership of ideas is clear and opportunities are provided to express their relationship to it.

This group of students provided evidence that shifts in identity and ownership can take place readily and meaningfully. We examined evidence of ownership and identity through the discourse surrounding learning moments that stand in contrast to less robust efforts like simply hanging posters for women in science or hosting a "Meet a Black scientist day." We examined the notion of the "other" framed by Harre, Rommetveit, Bakhtin, and Glasersfeld who referred to the other as a construction necessary to give meaning to utterance. Bakhtin argued that in order to engage in meaningful communication one must remain distinct from, and in a manner of speaking "*outside* of, *one's other*" – that is, a dialogue is possible, only when we remain different from our "others" (1986, p. 155). We believe that looking at lower-track students' interactions with "others," specifically those noted as "scientific," can give a desirable insight into the lasting nature of the outcomes of constructing this third space. To establish this point of identity and ownership of science knowledge and further establish identity in contrast to the *other*, we turn to another event where local scientists were asked to come and talk about their work with students.

Often with underrepresented science students, speakers are invited to talk with students who share a similar culture or ethnicity to encourage them to pursue science. For example, when these students were told that a local meteorologist was going to visit the classroom and speak with them about the science of meteorology, students began watching and recording media broadcasts and logging their accuracy. For three weeks students maintained a chart of the daily forecasts, organizing them into 5-day, 3-day, and 1-day forecasts for each day of the month. In this way, all 5-day forecasts could be analyzed for their accuracy and each day examined for the trends in forecast toward the actual weather on that day. Students created their own rubric for assessing the match between forecasts and actual weather conditions and prepared questions for the speaker upon their arrival.

The visit began as most would expect from outside science experts visiting the science classroom. The meteorologist talked about his passion for weather, when it all began, things he liked about his job, and some of the cool tools he worked with regularly. Students asked him if meteorology was a science and he said “absolutely” and proceeded to talk about all the different kinds of science topics one needs to know to predict weather and what courses/training he had attended to do his current job. After a long and comfortable show-and-tell format, the speaker was then invited to listen to the students’ analysis of his forecast accuracy. Three students spoke about their methods of collecting daily forecasts and documenting how they changed over the course of a week for each day prior to his visit. They reported that a 1-day forecast was obviously the most accurate (rating better than 55% accuracy) while the 3-day forecast was only likely to be accurate one in three times. Students were very concerned that the forecast 1 week out was less than 50% accurate. Students’ prior class discussions about accuracy and precision were brought to the conversation implying that their standard of 10% error measurements and discussions of astrological prediction suggested meteorology to be less than “scientific.”

Student 1: Your predictions were only half right on your fives. How come you can’t get it right?

Marvin: Well, meteorology has a lot of different factors you have to know that impact our daily weather. It’s not just one thing or another. It’s a whole collection of things.

Student 2: But you said this was *science*…?

Student 3: Yeah, that is less than the coin toss activity we did!

Student 4: Why don’t you just hire me… (Even) I can flip a coin?! [class laughter]

Although we do not condone any disrespect toward outside visitors or science experts, we do feel that such a challenge is a direct indication of the ownership over ideas and science expertise resulting from authentic study conducted in an alternative third space for lower-track students. Students were bringing standards for accuracy and precision that they had been required to use in classroom conversations and critiques of one another’s claims, and applying them to the visiting expert. Perhaps the laughter and challenge is a result of the antiauthority identity these students share or perhaps it was a nervous laughter regarding the boldness of one student to speak to what many saw as a contradiction. What seems clear is their astute recognition of science standards and their willingness to apply these standards found in the book to an expert demonstrate that even scientific standards for accuracy have become a part of their thinking toward classroom members and outsiders.

Lasting shifts in these students’ identities as science experts expanded beyond their own classroom as they were called upon by teachers outside their science class to help teach linear regression techniques on their TI–83 calculators, according to one advanced algebra teacher commenting on their surprise of specific students’ willingness to be the expert among *others*. In addition, these same students turned over their study to the AP Statistics class who was given a copy of the lower-track students' analyses of forecasts and asked to comment on the strength of the study. There was great pride in the work from these lower-track science students and it was not uncommon for the AP Statistics class in the future to comment on the topics and projects occurring down the hall in the earth science class. Practitioners will recognize the rarity to AP students knowing the goings-on in lower-track science classes to the point where weekly they comment on their curriculum, tasks, questions, and projects. We were told by the AP Statistics teacher, "Oh yeah, they tell me all the time what they are studying. They know, and they're always asking."

Rethinking Needs and Requisite Knowledge

In this chapter we have attempted to offer an alternative interpretation of why marginalized students continue to not engage in science and school at large and offer an alternative framework to interpret successes and failures to remedy the problem of equitable science education for a diverse student body. We have shown how students with long histories of failure have chosen to engage in the discourse norms associated with many explicitly stated reform goals (e.g., higher-order thinking, interpretation of data, construction of arguments about real-world events) while maintaining their cultural identities. Students have been engaged in asking and answering their own scientific questions, they have chosen to take risks to reengage in the education process, and they have engaged themselves in the process of defining and owning an authentic version of scientific expertise that parallels the best of scientific communities. Finally, we have demonstrated the usefulness of Bakhtin's work to understand the nature of the necessary shifts in classrooms to support meaningful dialogue and construct a third space in which teachers and students can reestablish a less contentious and more collaborative approach to science teaching and learning.

This approach emphasizes the teaching where students are taken through the process of asking questions, gathering evidence, constructing arguments, and ultimately claiming authorship over scientific representation. We acknowledge that practical and ideological shifts of this kind take much time and effort because reestablishing trust and mutual engagement to connect to lower-track students requires rethinking what science discourse looks like. It requires the recognition and the response to acting, thinking, and speaking cues to what shifts need to be made when two separate camps look at the world from such different perspectives. We want to also explicate that shifts occur not only when student roles and participation are reoriented in the minds of educators but when their own views of their roles as educators are reoriented away from the content deliverer, lecturer, manager, disciplinarian, or tester. Teachers must think as much about their own predispositions toward lower-track students as they think about changing their students' predispositions toward science. These shifts are nontrivial; as we read Bakhtin's work we cannot separate our ideology from our utterances.

Our intent is not to incriminate or blame any teacher who responds differently to the antisocial behaviors of challenging students. We recognize that many lower-track classrooms are set up for failure from the start. So often the least prepared teachers are given the most difficult teaching loads. Common knowledge in school suggests the most inexperienced teachers often have the least input regarding their teaching schedules and the likely scenario is the most preps with the toughest kids. These students also arrive into the classroom with an entire identity kit intact, which has likely been formed over years of failure, marginalization, and intentional distancing of themselves toward school authority figures.

It is a complicated scenario and one that may seem daunting to open other ways of thinking about marginalized science students. We suggest that teacher education programs bring in a wider array of research orientations toward learning to teach science. Teacher educators should embrace the notion that science can be represented as multiple discourses and that many different facets of learning can and should constitute a teacher's knowledge base. Teacher education programs should underscore how teachers can build a context which values the student culture that is typically disparate from their own as teachers – a microculture they may not value at first glance. Embracing a new approach to learning as illustrated above would allow teachers and researchers not only to uncover new processes for learning but also uncover new potential and long-lasting benefits for marginalized children to become lifelong students of science. Transforming classroom discourse also requires something typically not supported in public schools. It requires risk. It is risky to lay down old established rules because any shifts in rules can be interpreted by students or administrators as the lack of any rules at all. It requires the willingness of both parties to lay down their power exerted in this environment. But when has making important shifts in anything never involved some degree of risk?

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Chapter 92
Understanding Beliefs, Identity, Conceptions, and Motivations from a Discursive Psychology Perspective

Pei-Ling Hsu and Wolff-Michael Roth

In science education, psychological (rather than sociological) frameworks play central roles in guiding investigators to theorize and conduct their research objects. For instance, Jean Piaget's theory of cognitive development has been used for decades to understand the benefits of hands-on learning, Benjamin Bloom's taxonomy still is used to articulate behavioral objectives and learning outcomes, and Ernst von Glasersfeld's radical constructivism still contributes widely to science educators' understandings of learning. Recent developments in the social sciences have allowed a form of (social) psychology to emerge that takes a different avenue to understanding psychological phenomena including cognition, affect, beliefs, identity, conceptions, and motivations: discursive psychology. The purpose of this chapter is to articulate and exemplify this theoretical framework relatively new to and not yet widely used in science education.

Only a decade ago, Harold Garfinkel (1996) asked the thought-provoking question, "What more [is there to social scientific research]?" His "what more?" did not concern more of the same type of *formal analysis*, almost all of the existing quantitative and qualitative methods, but a recognition and utilization of the *methods* of analysis that people (*ethno*-) themselves deploy to realize everyday immortal society in general and science classes in particular. Discursive psychology is one such alternative that provides science educators an additional framework for understanding science teaching and learning. In the following section, we begin by introducing discursive psychology, concretely (practically) demonstrating its method of analyzing talk in science-related contexts. We then move on to suggest how present science educators may use the tool

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to generate new insights about beliefs, identity, conceptions, interest, and motivation in and for science education. We both propose and advocate discursive psychology as a rigorous tool (theory and method) that offers new possibilities to science educators for taking their research into new directions.

Analyzing Interview Data from a Discursive Psychology Perspective

Following Piaget's pioneering studies in developmental psychology, researchers examined children's cognitive development through careful experiments and interviews. In such research, children's understandings of the world have been taken to be coherent, internal cognitive representations (Edwards 1993). In experimental manipulations, language has been treated as an apparently neutral means for getting at the presupposed underlying cognitive states. Edwards suggests that such researchers are taking language to be a window through which one can look at the thoughts in and of people's minds. In the meantime, psychologists also traditionally attempted to produce a psychology of people trying their best, in a disinterested and noncontingent manner, to recall information from memory, articulate beliefs and attitudes, give researchers access to their identities, and so on. But, one might ask, how do psychologists come to talk (know) about the minds (memory, beliefs, attitudes) of people?

Psychologists often claim that they use scientific experiments to accurately "detect" entities (e.g., intelligence, attitude) *out there* in people's minds as if they are scientists to "discover" and "invent" names to label objects *out there* in the natural world. But actually "psychologists did not invent the concept of *emotion*, for example, to account for certain empirical findings; they obtained certain empirical findings because of their desire to investigate a set of events which their *culture* had taught them to distinguish as *emotional*" (Danziger 1997, pp. 5–6). That is, psychologists often overlook cultural resources such as language and transform *their* empirical findings directly into psychological categories as stable entities in people's minds without incorporating how psychologists themselves (as human beings in general) learn these psychological topics in the first place – by talking psychological topics with others. As researchers we do not have to assume the contents of others' minds to understand these psychological topics but rather, we can follow people in relevant contexts to investigate how they use culture resources – language itself for talking about psychological topics. This, then, is the theoretical and methodical starting point and ground for discursive psychology: how, when, where, and why does everyday talk mobilize psychological concepts (memory, cognition, attitudes, affect, beliefs, identity, conception, and motivation)? Discursive psychology thereby has taken psychology into a radically different direction because it understands the role of language in human endeavors very differently (Edwards and Potter 1992). The approach evolved from Ludwig Wittgenstein's (1958) later philosophy on language as a set of games people play, ethnomethodology (e.g., Garfinkel 1967), rhetoric (e.g., Billig 1985), sociology of science (e.g., Gilbert and Mulkay 1984), conversation analysis (e.g., Atkinson and Heritage 1984), and discourse analysis (e.g., Potter and Wetherell 1987). Interested in the role language plays in participating and learning in human societal activities, discursive psychology constitutes an approach for studying the phenomena of psychological concepts in the way interaction participants use them to manage public affairs with stakes or interests in discourses.

Analyzing Interviews: Finding Underlying Beliefs and Attitudes

To provide practical illustration of the unique characteristics of discourse analysis, we begin with a demonstration of how discursive psychologists analyze interview transcripts (i.e., a form of data sources that science education researchers commonly use). The following interview fragment was taken from a series of interviews conducted to understand the discourses about future careers drawn on and realized by high school biology students. The fragment is part of an episode where the interviewer asked the student Claire to talk about her preferred career interest: becoming a doctor. Before the fragment, Claire already articulated that she used to follow a doctor around in a hospital; this experience mediated her interest in becoming a doctor in the future. The fragment begins when the interviewer asks the student further questions.[1]

```
01 I: so you know more?
02 C: yeah.
03 I: and now you like it more? ((laughs))
04 C: i like it a little more, like last year i did not
      like it
05 I: oh: REALLY, WHY?
06 C: i don:t know, because (1.58) i think i was watching
      like (0.95) some shows on how hard it is, right?
07 I: mm, for example? what kind of situation you [don:t
      like]
08 C: [just just] schooling, seems to pretty:
09 I: oh:: i see (.) you have to take a lot of [courses ]
```

[1] We draw on Jefferson's (1984) notation for transcribing the episode. Brackets ([text]) indicate the start and endpoints of overlapping speech; Period (.) indicates falling pitch or intonation; Question mark (?) indicates rising pitch; Comma (,) indicates a temporary rise or fall in intonation; Period inside single parentheses (.) indicates a brief pause, usually less than 0.2 s; Numbers inside single parentheses (# of seconds) indicate the time, in seconds, of a pause in speech; Capitalized text (ALL CAPS) indicates shouted or increased volume speech; Colons (:::) indicates prolongation of a sound; Text in double parentheses ((text)) indicates annotation of nonverbal activity.

```
10 C: [a lot of] courses (.) and i don:t know if i can
      handle that though (.) because my cousin tried
      taking some of the courses but he (.) it was too
      much for him (.) so::
11 I: um:: so he give up?
12 C: yeah he give up
```

In this fragment, Claire articulates that, although being a doctor is one of her preferred careers, she still has some concerns about this occupation including issues of "schooling" (turn 08) and "[taking] a lot of courses" (turn 10). In traditional studies of students' science interests and motivations, it would not be uncommon to see such data being used to make attributions to Claire. In the episode, for instance, researchers might ask "*why* does Claire have these concerns about being a doctor?" The answers to *why* kind of questions would lead researchers to identify *factors* underlying Claire's responses that serve as predictors of science attitudes (see Stake 2006). For example, such researchers might suggest that Claire has been subject to *public media influence* ("watching [TV] show" [turn 06]) or *family/peer influence* ("my cousin" [turn 10]). Traditional research also identifies *psychological entities* that may serve as predictors of students' science grades (see Britner 2008) such as *self-efficacy* or *beliefs*. Thus, in the present fragment, Claire might be identified as not having high levels of self-efficacy because she said, "I don't know if I can handle that though" (turn 06).

The Ethno-Methods of Doing Interest Talk

Discursive psychologists analyze data in a radically different manner from such approaches. Instead of asking *why* questions and attributing people's discourse to underlying factors or psychological features, discursive psychologists ask *how* questions and take discourse as its own topic. They tend to analyze *how* people use language (especially the use of psychological terms) to achieve particular soci(et)al practices in that context (e.g., interview). Here we demonstrate how discursive psychologists analyze this same episode but focus on very different aspects of the interview discourse without attributing to people's intentions (e.g., what they think, know, and understand).

After Claire articulates her previous experiences of following a doctor around, the interviewer asks the question, "so you know more and now you like it more" (turn 01–03). We observe that the interviewer uses psychological terms "know" and "like" and a positive correlation "more… and… more" to articulate a conclusion derived from Claire's prior talk. As a participant in the setting, the interviewer states a possible correlation between Claire's cognition and affect. The issue for discursive psychologists now is not whether and how cognition and affect are correlated *within* Claire's mind but rather how Claire and the interviewer manage to make or dissociate from such a correlation. To understand the unfolding of the interview, all resources analysts require are indeed the same resources that participants themselves provide.

Claire responds by adjusting the interviewer's assertion to "like it a little more" (turn 04). Claire does not use "no" to reject the interviewer's statement, but uses "little more" that does not reject or agree but has both functions at the same time. That is, the adjustment "little more" allows Claire to *reformulate* the interviewer's conclusion without creating a directly conflicting statement (perhaps taking a risk to offend the interviewer). Claire then provides *evidence* for articulating such an adjustment "like last year I didn't like it" (turn 04) that describes a temporal period for her dislike. The interviewer further asks "why?" (turn 05) and Claire first answers "I don't know" (turn 06), which indicates that she does not yet have an explanation ready to hand. But then, she says "because I think" (turn 06) followed by an elaboration. Here, we notice that Claire originally does not "know" why she disliked being a doctor last year, but after a conversationally long pause (1.58 s) she then, apparently spontaneously, comes up with an explanation here and then. She uses the adverbial and conjunctive "because" to articulate her *reason*. This is especially evident that Claire uses a present tense "think" (rather than the past tense "thought") that indicates Claire's formulations of what she is doing at the moment – *thinking during the interview*. That is, Claire is producing an after-the-fact rationale *during* the interview and allows it to be heard as a cause (be*cause*) for a previous dislike (last year) to respond to the interviewer's "why" question. This account is rendered for the purposes of the interview. It, therefore, has to be understood in terms of its dynamics and requirements for *doing* the interview rather than as a feature of Claire's psychological makeup.

From turn 01 to the beginning part of turn 06, there is an important message for researchers to rethink the issue of cognitive entities. That is, an interviewee does not need to have a "reason" or "mental model" beforehand to answer a question but can spontaneously generate a plausible answer and make it like a causal reasoning *during* the interview for justifying her *interests* (i.e., "because I think I…"). This message has significant implications for science education in particular, as the existence of mental models (conceptions) in the minds of students and teachers is a dominant presupposition (Roth et al. 2008). That is, conceptual change researchers aim to study and change students' and teachers' (mis-/alternative) conceptions that exist somewhere in people's minds rather than possibilities that come with their language. However, when we take a closer look at the micro details on how people articulate and interact, we find that people always enact and talk differently in different situations. It is, therefore, not surprising for us to hear that researchers might collect different kinds of "(mis-) conceptions" from the same participant by means of interviews, questionnaires, or tests because of the contingent nature of different discourses employed across settings. Thus, we purport that parts of contributions from discursive psychology are to help researchers challenge or question these generally invisible assumptions underlying science education research.

Reaching Consensus

In part, discursive psychology is interested in how people use talk to arrive at consensus concerning their topics of talk. The results of such investigations clearly show how topics are collective achievements and not the residues of individual minds.

Take, for example, the latter part of turn 06 where Claire makes her explanation (about disliking being/becoming a doctor) available to the interviewer ("I was watching like some (TV) shows on how hard it is, right?"). Here, we can hear not only how Claire provides an explanation but also how she ends with a tag question ("right?"). Such a question puts the other party in a position that requires an answer. We might ask, "Why does Claire need to propose a question here?" Claire is an interviewee and she is supposed to answer rather than ask questions. However, in the situation, we can hear her tag question as an offer for articulating *consensus* between the two participants (Edwards and Potter 1992). That is, the tag question opens a space for the interviewer to confirm, in one way or another, the preceding talk that was offered as the completion of a query–explanation pair. After responding with what can be heard as an affirmative "mm" (turn 07), the interviewer asks for an example (turn 07). Claire then says, "schooling" (turn 08). Responding with a comprehensive comment "oh, I see" (turn 09), the interviewer then offers a description of schooling ("you have to take a lot of courses" [turn 09]) as an explanation candidate. Here, the interviewer does not only say "courses" but "a lot of courses," which particularly emphasizes the quantity of courses in an extreme way. The *extreme case formulation* (Pomerantz 1986) is a way to legitimate claims. For instance, saying "a lot of courses" allows the interviewer to point out an intelligible reason for not wanting to become a doctor.

Claire then comments that she does not know if she can handle that "because my cousin tried taking some of the courses but it was too much for him" (turn 10). Here, we, the analysts, in the same way as the interviewer, not only can hear Claire no longer talk about previous experience, but also witness the inclusion of another person's experience – her cousin. He had been taking courses but, as Claire suggests, "it was too much for him." Here, by drawing on another person's similar view, Claire builds a witness case that can make a strong *corroboration* (Potter and Edwards 1990) in support of her claim: the schooling required for becoming a doctor is hard. Moreover, Claire's descriptions about her cousin's experience make a clear contrast: "my cousin tried taking *some* of the courses *but* he, it was *too much* for him." That is, using a small number of courses ("tries taking some") at the beginning to which is added a disjunctive conjunction "but" followed by a high quantity of stress ("too much for him") construes a *contrast* (Heritage and Greatbatch 1986) that makes her witness case even stronger and justifiable.

Section Conclusions

Our case exemplifies how discursive psychologists take psychological phenomena such as interest or self-efficacy as *topics* of talk rather than as features of mind. That is, discursive psychologists are interested in identifying people's language deployed in performing certain social actions rather than identifying people's cognitive or affective entities in their minds. When Claire mentions her cousin, discursive psychologists articulate it as a device to make Claire's statement reliable and convincing in the interview context by including a witness case rather than suspend it as a *family/peer influence* on Claire's *self-efficacy* or *belief*. That is, discursive psychology only focuses on what participants make available to one another in that concrete situation but do not make attributions to individuals' minds forever inaccessible to others and to analysts. These devices are shared cultural resources that interlocutors draw in managing both their interaction and the topics of talk. That is, language rather than people is the focus of the analysis. The people all but concretize the possibility that exists in and with the language.

The main task for discursive psychology is to articulate how psychological topics are mobilized in and for everyday interactions. In addition to the aforementioned topics, discursive psychologists do not consider social categories such as gender, age, race, class, or institutional identity into their analysis unless participants themselves articulate them or make them available for analysts, as these social categories are like "categories of professional judgments" (Bourdieu 1992) that researchers generally use without questioning. Focusing on language-in-use and featuring data transparently (i.e., transcribing very details of conversations) makes discursive psychology a rigorous and reliable approach (theory and method) for understanding society in the making, including science lessons and research interviews.

New Insights in/for Science Education

With regard to the unique nature of discursive psychology, researchers have started using it as a new tool for rethinking traditional science education topics in new ways including beliefs, identity, conceptions, interests, and motivations. In this section, we illustrate how science educators presently apply discursive psychology to investigate science-education-related situations. We thereby provide an outline of what answers to the question "what more?" can contribute as insights in and for science education.

Interpretative Repertoires for Talking Science Epistemologies and Beliefs

The concept of *interpretative repertoire* first appeared in a sociological study of biochemistry laboratories in the UK and in the USA (Gilbert and Mulkay 1984). The authors found that scientists employ certain stable interpretative forms of talk with great flexibility to generate radically different accounts of social phenomena. They identified two interpretative repertoires: empiricist and contingent repertoire. The empiricist repertoire usually happens in the formal discourse (e.g., conferences) where scientists use impartial and objective words to support their articulation like "the experiment confirmed…" or "the results show…," and so articulate scientists as objective and as following particular experimental procedures that lead to the factual results. However, scientists also described themselves as social beings whose work is sometimes affected by their desire, beliefs, and prejudice. Gilbert and Mulkay termed this the *contingent repertoire*. It was generally found in informal settings (e.g., interviews) or when things go wrong where scientists use many interpersonal words (e.g., "Dr. Smith believes that…" or "the result must result in human errors…"). Sometimes the two repertoires led to contradictions, such as when the same scientist claimed only minutes apart that science is both socially contingent and objective. In this case, special *discursive devices* were invoked to resolve them. Thus, for example, the *truth-will-out device* (TWOD) allowed scientists to talk themselves out of the contradiction that science is both contingent (subjective) and objective.

Interpretative repertoires therefore can be defined as "the building blocks speakers use for constructing versions of actions or cognitive processes" and are "constituted out of a restricted range of terms used in specific stylistic and grammatical fashion" (Whetherell and Potter 1988, p. 172). Interpretative repertoires are also part of any community's common sense and are available to any member of a culture, providing a basis for shared social understanding. Thus, identifying interpretative repertoires in science discourses allows researchers to better understand the culture and ideology shared in certain communities including science classrooms or environmentalist groups. In science education, the major works employing interpretative repertoires include:

– Studies designed for understanding students' discourses about ontology, epistemology, and sociology of scientific knowledge. One study identified nine interpretative repertoires that students used to support their more tentative claims about the nature of scientific knowledge: *intuitive*, *religious*, *rational*, *empiricist*, *historical*, *perceptual*, *representational*, *authoritative*, and *cultural* repertoires (Roth and Lucas 1997). In addition to these interpretive repertoires, students drew on a variety of discursive devices to mediate the conflict between repertoires including the "as-long-as-it-works-take-it-as-truth" and "truth-will-out" devices (Roth and Alexander 1997). These studies show that it is important to know *how* students draw on repertoires to ground their claims about science epistemologies or beliefs, for they may articulate very different epistemological stances employing the same interpretative repertoires.
– A study to understand how environmental educators account for their curriculum design (Reis and Roth 2007). Five interpretative repertoires were identified: *relevance*, *knowledge transferability and translatability*, *emotionality*, *expertise*, and *empiricism*. These interpretative repertoires help researchers to understand how environmental educators articulate *why they do what they do* and *how they do what they do* for designing environmental curriculum and so illustrate the common ground and ideology shared in the culture of environmental educators.
– A study of the discourse to introduce authentic science activities (e.g., internships) to students. Six interpretative repertoires were discerned in a real-time classroom discourse (Hsu and Roth 2009): *specialized*, *a-stereotypical*, *relevant*, *empirical*, *emotive*, and *rare-opportunity*. Importantly, when students were asked

for their rationale for participating in these science activities, they drew on similar interpretative repertoires that appeared in their teachers' introduction discourses. That is, their discourses about these science activities produce and reproduce the discursive resources as historical-cultural phenomena.

– A study of Swiss junior high school students' discourses concerning environment and environmental protection (Zeyer and Roth 2009). This study identified three main repertoires similar to the ones offered in previous research: *evidence*, *intuitive*, and *agential* repertoires. The agential repertoire can be seen in two areas of tension giving rise to two additional, second-order repertoires. One repertoire emerges from the tension between the ideal and real, whereas the other arises from the tension between self and others. The repertoires explain the post-ecological discourse observable in Swiss society as a whole.

Identifying these interpretative repertoires in science discourses is important because they allow researchers to identify general resources shared within communities not only in schools and among students but also within culture more generally. Moreover, the interpretative repertoires are associated with a high degree of ecological validity for applying in everyday conversations such as in classrooms, because they are in a practical form of language itself rather than in an abstract form of theoretical or psychological formulations.

Understanding Identity in and Through Discourse

Identity has become an important topic in science education for understanding science teaching and learning (Roth and Tobin 2006). However, the complex nature of identity makes this a difficult topic. Discursive psychology can be used to identify the rhetorical devices by means of which identity and self-representation are realized in conversations for the purposes at hand. For instance, a study designed to understand how the identity scientists came about in interviews showed how rhetorical devices such as "stake" and "footing" are employed (Lee and Roth 2004). Take *footing* as an example: an individual scientist sometimes uses plural pronouns "we" or "scientists" (rather than "I") that allows the individual to distance him-/herself from possible blames or to minimize his stake in case his assertion is incorrect (e.g., "scientists speak over people's heads"). That is, by shifting in different pronouns in his talk (footing), a scientist can manage his identity talk to be justifiable, rational, acceptable, or believable and so making his scientist identity as objective, passionate, expert, and disinterested.

In addition to these rhetorical devices, discursive resources have been identified to support identity talk. Thus, a fish culturist articulated his expertise by drawing on a *workplace repertoire* that construes him as a person of modest education with much hands-on experience who could solve problems on the ground; the *school repertoire* allows the treatment of knowledge and learning as abstract and theoretical with minimal concrete relevance to everyday life in the hatchery (Lee 2007).

Furthermore, a study in urban high schools shows that identity talk can be understood in terms of the discursive contrast between two contrasts: (a) between talk about "same" and "other" and (b) between talk about the "material body" and "person" (Roth 2006). The first contrast articulates the difference between being caught up in and practical understanding of the world. The second contrast opposes the material body of a human being with its personhood. Each term that appears within one contrast can be applied to another contrast giving rise to a new form of device employed in the realization and production of identities.

Rethinking Science (Mis)Conceptions, Interests, Motivations

Studies of students' (mis-, alternative, pre-, naïve) conceptions and conceptual change have dominated the science education literature for over three decades. The general assumption in these studies is that people hold stable mental models in their minds and conceptual change researchers aim to change these mental models from the *wrong* ones to the *correct* ones. There is increasing evidence, however, for the contingent nature of discourse, which questions the theoretical formulations underlying conceptions and conceptual change research. For instance, having a globe nearby in situations where children are interviewed about the universe leads to radically different claims about what children know (Schoultz et al. 2001). Previous research concluded that many children have misconceptions about astronomical concepts, such as the shape of the earth and gravitation, whereas Schoultz and his colleagues show that there is no misconception talk following the same interview questions when a globe is present. That is, the presence of misconception talk was actually an artifact of method of previous research.

Influenced by discursive psychology, science education researchers start becoming aware of these issues. In science classrooms, for instance, researchers found out that there are numerous variations in students' discourse on the same scientific concepts within and across contexts even after teachers' instructions (Roth et al. 2001). This result indicates that students respond and interact with others differently (e.g., researchers, interview questions, written tests) in terms of different physical, social, and available resources in particular situations. The reported *systematic* inconsistencies in students' discourses about scientific concepts challenge the assumption of fixed mental models lodged somewhere in students' minds. In particular, the direct evidence obtained from participants themselves shows that people do not need to have a mental model beforehand to explain a particular nature phenomenon but it is *language* that provides them with resources to provide answers (Roth 2008). For example, Claire says "I don't know, because I think… (turn 06)." She makes a plausible *reason* at that moment to talk *to/for/with* the listener (interviewer) *during* that situation (interview). The awareness and need of rethinking the issues of (mis-) conceptions is salient in 2008 Volume 3 (2) of *Cultural Studies of Science Education* entirely devoted to this question.

Besides issues about cognitive entities, science educators have also started drawing on discursive psychology to address how affective issues such as interests and motivations are mobilized in settings of interest to science educators. For example, in interviewer–student conversations about career interests (Roth and Hsu 2008), students always orient to the listener (i.e., the interviewer) and their talk is mediated by the context (i.e., available tools, interview environment). They use a language not their own, together with the topics it enables such as interests and motivations, speak it for the other (interviewer), and thereby return the language (the topics) to the other. Moreover, the interviewer questions and artifacts already frame the discourse participants to the event draw on. That is, what researchers called *interests* and *motivations* are actually the collective products negotiated and constrained in the interview discourse (including interviewer, interviewee, and its interview context) rather than students' *own* interests and motivations. In other words, instead of taking *interests* and *motivations* as entities in people's mind, they can be thought of as discursive resources mobilized and managed for social actions and accountability.

Coda

In this chapter, we show how discursive psychologists analyze discourse without attributing it to forever-inaccessible structures in people's minds. This comes with new opportunities for science education research and praxis. Rather than focusing, for example, on children's misconceptions about the sun and earth, science educators can use discursive psychology to study how language itself provides the resources to achieve topical conversations. An utterance from an everyday conversation such as "this is a beautiful sunrise" where agency and movement around the earth is attributed to the sun may serve a child as a linguistic resource for explaining the concept of "day and night" without having previously thought about and constructed a framework to respond to such a question. That is, discursive psychology only makes claims that are observable and therefore challengeable by readers. In fact, discursive psychologists have raised the question of the problematic reductionism existing in psychological research, which normally uses experiments, questionnaires, tests, or interviews to detect people's complex relationships with the natural world and then transform and reduce data sources into factors or causes to explain people's behaviors (Edwards and Potter 1992). Having discursive psychology in their cultural tool kit, science educators now are in a position to begin a serious rethinking of their presuppositions about mind and language. They now can seriously rethink their ways of conducting research, analyzing language-in-use, and providing advice to teachers on the features of student talk that they ought to attend to.

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Part XI
Research Methods

Chapter 93
Qualitative Research Methods for Science Education

Frederick Erickson

This chapter on qualitative research methods in science education is divided into four major sections devoted to (1) the purposes of qualitative research, (2) data collection, (3) data analysis and (4) preparing reports.

Purposes of Qualitative Research

The essential purposes of qualitative research are to document in detail the conduct of everyday events and to identify the meanings that those events have for those who participate in them and for those who witness them. The emphasis is on discovering *kinds* of things that make a difference in social life; hence, an emphasis is placed on *qualitas* rather than on *quantitas*. This priority of emphasis does not mean that information about frequency is irrelevant to qualitative inquiry, for good qualitative research reports the range and frequency of actions and meaning perspectives that are observed, as well as their occurrence, narratively. The crucial problem for the qualitative researcher, however, is determining the "qualities" of social action and meaning.

Qualitative research in education is especially appropriate when we want:

- Detailed information about implementation
- To identify the nuances of subjective understanding that motivate various participants in a setting
- To identify and understand change over time

Human social action and opinion are locally distinct and situationally contingent. What at first glance can seem to be the same sort of setting, event, or point of view

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can be subtly different in kind despite surface similarity. When we are not certain about the details of local implementation of educational practices, then documentation through qualitatively sensitive narrative description is necessary. We need to be able to answer the question "What was the treatment, specifically?" before we try to answer the question "What were the effects of the treatment?"

At the most fundamental level, we need to determine whether or not the intended program was implemented in its most ordinary and material aspects. Were there classrooms and teachers available? Were the classrooms equipped adequately (e.g., with laboratory tables)? If there were tables, did their water taps and sinks work properly? Were the teachers prepared for the new teaching methods and materials? Did the books get published in time and did they actually arrive at the classrooms when the school term began?

At a more subtle level, we can study implementation by observing and documenting classroom discourse and pedagogy (e.g., Roth and Roychoudhury 1993). For example, in the newer "constructivist" approaches to teaching science and mathematics, the emphasis is on the students' construction of knowledge. To encourage such an active stance toward learning, we in the USA assume that a teacher leading a class discussion would avoid entirely, or at least use quite infrequently, traditional "teacher questions" (i.e., known information questions in which the teacher knows the answer and the students know that the teacher knows). However, because of the power of customary cultural expectations of both teachers and students, it is difficult to change these conversational patterns in classroom discourse. If classroom discussion involves the teacher and students continually sliding back into their old habits of known information questions and emphasis on procedural correctness for getting the right answer, we could say that the new "constructivist" curriculum was not actually implemented, even though everyone went through the motions of implementation.

Two examples of questions that are too general in focus to be useful to inform educational practice are: "Did the teachers like it?" and "Do the students understand it?" Which teachers liked or disliked what aspects, in which situations? Some kinds of dislike can come with unfamiliarity, while other kinds of dislike stem from a sense that the teacher's identity is being violated in following recommended practices. This can involve the teacher's identity as a professional, as a man or woman, as a member of a certain social class or ethnic/religious identification group, or some combination of these (e.g., Glasson and Lalik 1993).

Which students understood what, in the doing of it and after the fact of doing? Much qualitative research in science education has been motivated by the desire to gain more specific understanding of the cognitive processes by which students understand and misunderstand science content and its discourse (e.g., Roth 1994). Here, too, as with the issue of likes and dislikes, identifying what science content "means" to varying students involves probing subtle differences, especially the distinction between literal, referential meaning and more metaphoric social meaning. A student can "understand" the periodic table cognitively in a literal way while also "understanding" that such knowledge feels alien – that knowledge has become a metaphor for *not me*. The entire understanding of the student involves a combination of both referential and social meaning. This is to say that, in teaching and learning science, there are always issues of hidden curriculum combined with manifest curriculum, for students and for teachers as well.

The understandings of members in the setting, while the central focus of qualitative inquiry, are not considered uncritically by the researcher. There could be contradictions between intentions and actions and there can be systematic blind spots in the awareness of both teachers and students. Part of the responsibility of the qualitative researcher is to go beyond what the local actors understand explicitly, identifying the meanings that are outside the awareness of the local actors, and revealing the hidden curriculum so that it can be faced critically by teachers and students (see especially Lemke 1990). There is also the issue of curriculum integration – intended and unintended. For example, science can be a rich environment for the acquisition of literacy skills (Florio-Ruane 1982), but many teachers might not realize this.

Teaching and learning in science education are discursive activities (Lemke 1990). By *discourse*, I mean both its small letter "d" sense and its large letter "D" sense. In the small letter "d" sense, discourse refers to the conduct of immediate social interaction by verbal and nonverbal means. Science is talked and written in words – its ideas are not only expressed in numbers. Learning science is learning a new dialect and, as with the acquisition of other aspects of language, learning the dialect of science occurs in face-to-face conversation with others. Which kinds of classroom conversations appear to offer especially rich opportunities for understanding science? Which conversational roles appear to be most productive for students and for teachers? Sociolinguistically informed microanalysis of classroom discourse, in the small letter "d" sense, offers much potential for study of the acquisition of scientific understanding.

Discourse also has a broader meaning, in a large letter "D" sense. Learning is not only a matter of participation in an immediate conversation, but it also involves joining in a larger Conversation whose interlocutors, language, topics, and political and economic interests range far in social space and time. To do science and to know it is to engage as an interlocutor in that larger conversation – with Newton, Einstein, and Heisenberg, for example, and with their financial patrons – King Charles II of seventeenth-century England and the German and American governments and business interests of the twentieth century, including munitions manufacturers and what was to become the aerospace industry. To engage in the Discourse of science is to adopt not only a dialect, but a voice – a stance toward the phenomenal world and to society. In this larger sense, the Discourse of science can be thought of as the totality of knowledge and social situation that it takes to adopt successfully the roles of doing science, as a student, as a teacher, as a researcher, or as one who seeks and receives scholarly and financial sponsorship (Gee 1990).

Not everyone wants to buy into such roles – sometimes the risks might seem too great. All learning involves risk. Yet, to take the leap of risk as a learner, I think that there must not only be a safe and predictable learning environment, but also the learner must have a sense of entitlement, an audacity.

In societies throughout the world, the sense of entitlement is unequally distributed. Those from upper-class and middle-class backgrounds have more entitlement than do the very poor. For the already advantaged, the life project is progress – perhaps even advancement. For the very poor, the life project is survival – do not lose what you already have, and do not risk much because the stakes of trying and failing are so high. This might explain, in part, why constructivist approaches are resisted by some students, by some parents, and by some teachers. The ambiguity of not knowing a right answer or a right procedure is scary business for a learner.

I do not believe that it is impossible that those who have grown up in circumstances in which they and their parents have little power and little respect could dare to try at difficult school tasks. But I do think that they might need special encouragement and special safety in the classroom – the safety to be imperfect and in process (Erickson and Shultz 1991).

Scientific knowledge is power, as is all other knowledge, according to Foucault (1979). If we wish to change the distribution of scientific knowledge and prestige in society through a new kind of science education, then the study and practice of science education needs to address issues of the political economy and the semiotics of scientific knowledge and of its acquisition. The "meanings" of scientific knowledge and skill are deeply embedded in issues of power, risk, trust, legitimacy, and in-group/out-group distinction and ranking. Studies of student "misconceptions," which do not address issues of power/knowledge, seem narrow and shallow in comparison. They fail to mine the richness of meaning that is inherent in the study and practice of science.

Data Collection

Research as Searching

To do research is to pay unusually close attention and to reflect deliberately on what we have seen and heard. "Re-searching" is to seek and seek again, recursively. The basic issues in designing strategies for data collection are to think where we would need to be searching, with whom and in what relationships. Addressing such issues is necessary in order to gather evidence to warrant the assertions that one would like to be able to make in answer to the main research questions that have been posed in the study.

These issues – where to be as researcher, with whom, and how – have both intellectual and ethical dimensions. Because the literature on qualitative research has emphasized issues of data collection and research ethics, and because of the limitations of space, I do not discuss data collection in detail here. Rather, I state briefly a number of points, which I think are especially important. These points and more detailed discussion also can be found in other publications I have authored on qualitative research methods (e.g., Erickson 1986). In addition, I have found especially helpful the writings of Hammersley and Atkinson (1983), Miles and Huberman (1984), Clifford and Marcus (1986), Strauss (1987), Bogdan and Biklen (1992), LeCompte et al. (1992), Denzin and Lincoln (1994), Wolcott (1994), Denzin (1996), and Lareau and Shultz (1996).

Framing Questions

The research report will consist of answers to the questions, which one has framed; thus, good questions are at the heart of the inquiry. Of course, because settings are locally distinct, one cannot anticipate fully in advance the circumstances that will be encountered when the study has begun. Research questions, data collection operations, and research role relationships necessarily change during the course of a qualitative study. In spite of this it is useful to frame questions in advance and think of the kinds of evidence that we would want to have accumulated in order to answer those questions, as well as anticipating issues of ethics.

Variety in Sources and Kinds of Evidence

The participant observer uses two primary means of data collection: looking and asking. What people's doings mean to them might be apparent from looking, but often determining this also necessitates asking them by means of informal and formal interviewing. We also might need to ask because we cannot be everywhere in the present and because we cannot observe what has happened in the past. Yet asking is often more intrusive than watching, even when the asking is done very informally. The ideal process, in my view, is a recursive process of observation and interview in which, at each step along the way, insights gained by one method (either by looking or by asking) are followed up using the other method.

Looking and asking in a setting can produce differing sources and kinds of data, each with a distinct epistemological status as evidence: field notes written by an observer; interview comments; machine recordings; and site documents, including demographic and historical material. An effective data collection design includes as many of these different sources as possible, and always includes observation, interviewing, and collection of site documents and often including machine recording as well. As data analysis proceeds, when hunches about patterns that were developed on the basis of field notes are cross-checked and confirmed by reference to interview data or site documents, one has a stronger evidentiary claim than if evidence came from only one information source (the formal term for this is "triangulation"). Indeed, if we think of the evidence collected in a qualitative study that warrants a particular concluding assertion as consisting of information bits, an assertion warranted by 500 bits from field notes, 500 from interviews, 250 from site documents, and 250 from videotape analysis is more credible than an assertion warranted by 4,000 bits from interview comments or from field notes alone.

Thus, in designing data collection strategies one needs to anticipate the variety in kinds, sources, and amounts of evidence that will be necessary in order to draw credible conclusions and present them in a report. Data collection strategies can be planned in general at the outset. For example, in a study of the changing student conceptions of dynamics in a high school physics class, one can anticipate needing to observe class sessions firsthand (for a certain number of days over a number of weeks, or for a complete unit or topic of subject matter, or for an entire semester or school year) and possibly also needing to videotape on specified days – placing a wireless microphone alternately on various focal individuals in the class. One would want to interview students and the teacher outside of class. One also would want to collect student work (notebooks, scribbles on worksheets, and journals) for focal individuals and perhaps for the whole class. Perhaps, on a daily basis, this material might be photocopied and then handed back to the students (this could be done by arranging to use the photocopying machine in the school office immediately after the class meeting). One might also want access to school records for demographic and family information as well as for prior scores on achievement tests, comments by prior teachers, or attendance and credit accumulation information. In addition, one might want demographic and historical information on the neighborhoods of students, including census tract and block data. One also might wish to interview the parents of focal students.

Ethics and the Negotiation of Entry

Researchers are obliged ethically to anticipate what will be done in data collection, analysis, and reporting, and to explain to those studied why it will be done that way rather than some other. In order to negotiate entry and deal responsibly with the concerns of those who will be studied it is necessary to tell them how we plan to conduct the study so that they can consider and give us advice about what that will mean to them in convenience and in safety. Without such knowledge their consent will not be genuinely informed. Written agreements are helpful in specifying the conditions of research.

Risk

The primary ethical obligation of the researcher, as it is of the physician, is to do no harm. Since qualitative research does not involve biochemical intervention of the sort found in medical research, the risks of physical harm are minimal. Usually this is true also for risks of social harm. As most qualitative research topics in education are framed, ordinarily the maximum risk to school students, teachers, or administrators is that of slight psychological harm due to embarrassment or to anxiety concerning the possibility of embarrassment. Admittedly, sometimes more than embarrassment could be at risk (e.g., if student performance were to be revealed as extremely poor or as involving academic dishonesty or if teaching or administrative performance were to be revealed as gravely incompetent). In such cases, administrative or legal punishment might result from exposure through research.

The risks of embarrassment or of administrative sanction for those studied are greatest when research information is shared in the local setting itself. For example, if a videotape or narrative vignette portraying a teacher is presented at a national meeting of researchers, few if any consequences to the teacher "back home" are likely to follow. However, if the same tape or vignette were shown to that teacher's principal when the principal disagreed with the teacher's approach to teaching, the risk of harm to the teacher would be much greater. Explicit agreements with teachers *and* with administrators about the circumstances under which information will be made available from the research, locally and nationally, can reduce anxiety about being videotaped.

Informed Consent

Consent that is genuinely informed and without coercion reduces the risk of social harm because it affirms the dignity and respects the agency of those who will be involved in the study. My experience has been that those studied become most anxious when they do not know the real purposes, potential audiences, and substantive foci of the research, as well as the boundaries around their participation that can be expected. Qualitative research requires not merely grudging and passive assent, but active participation in and commitment to the research by those who are studied. The best way to achieve trust with participants in the research relationship is by being trustable as a researcher – forthright and specific about what will be involved in participation in the study and respectful of the character and rights of those who agree to participate.

Issues of access and consent can be especially complicated when the classroom teacher is the researcher. Roles with colleagues and supervisors need to be renegotiated and at least oral assent granted by them. For example, if a teacher or principal is studying her own practice, and she takes notes in a staff meeting that will be used later as a resource for evidence (perhaps becoming the basis for a narrative vignette of a portion of that meeting that would appear in the written research report), assent to that teacher's presence in that meeting *as a researcher* rather than as an ordinary colleague is ethically necessary. In practitioner research, just as in research conducted by outsiders to the school, it is necessary not only to gain general and collective consent for research that might involve other persons as non-focal research subjects (e.g., by a collective vote of staff in a meeting or, in the case of primary school children, by the school principal acting *in loco parentis*), but also to gain specific consent from those who will be studied as focal individuals – from parents (in the case of children of primary school age) and from the individuals themselves (in the case of older children and adults).

Conditions need to be negotiated for those colleagues being observed so that they are able to declare certain material off the record or on the record, or to declare certain material out of bounds entirely, and to know clearly when the practitioner-researcher's "research light" is on or off. For researchers who visit a school as outsiders, the "research light" issue is less complicated logistically and ethically, unless the outsiders are in the role of advocates and/or collaborators with those in the school. In that case, the same conditions for consent and for "research light" notification obtain for outsiders as they do for insiders who are conducting practitioner research.

Data Analysis

Finding the Data

In qualitative research, analysis is a boot-strapping operation in which, reflexively, assertions and questions are generated on the basis of evidence, and evidence is defined in relation to assertions and questions. Data analysis, informal and formal, begins as one is negotiating entry to the research site. It often continues in restudy after supposedly "final" reports are written. In a fundamental sense, data reanalysis never stops, and this is why it is sometimes so difficult for qualitative researchers to bring their work to closure.

Bodies of information are collected in fieldwork and are held in documentary sources in various media such as field notes, interview tapes, videotapes, and site documents. These are not yet *data* as they appear in raw form; they are more appropriately regarded as *resources for potential data*. The documentary sources contain many thousands of information bits, not all of which are relevant to the inquiry that is being conducted. Analysis consists in recursive review of information sources with a question or assertion in mind, deciding progressively which information bits to attend to further and, perhaps even more importantly, which not to attend to. This reminds me of an aphorism from the graphic arts that states that "to draw is to leave things out."

In experimental research, the decisions about what will constitute data are made in advance of data collection and analysis. In participant observational research, data analysis and data definition are largely a matter of post hoc decision making. Such decision making is not capricious. As in historical research, it follows certain principled lines.

The fundamental issue is determining the extent of generalization, not as one's assertions apply to settings beyond the one that was studied (i.e., to external generalization), but as the findings concerning patterns in the setting are supported by evidence from within the setting (i.e., to internal generalization which involves generalization within the case rather than beyond it).

Finding Assertions

One can start with a tentative, working assertion about a pattern whose generalization within the setting could be checked later. For example, in a study of student conceptions of physics, one might want to assert that students hold an implicitly

Aristotelian conception of dynamics at the beginning of teaching a physics unit. One can also start analysis by drafting a narrative vignette, or by presenting an interview quote that illustrates students' physics conceptions.

Taking the former course is to begin analysis narratively by telling a story. This is incipient analysis because any coherent narrative account contains within itself an implicit theory of the organization of the events that the narrative describes. Beginning qualitative researchers and even more experienced ones often find that stating assertions is intimidating; it is premature to state a conclusion, one thinks. In that circumstance, breaking into analysis through narrative is an appropriate strategy.

Searching Data Sources for Evidence

Whether one begins analysis by framing a working assertion, or by telling a story in first draft, the next steps are crucial. They involve testing the evidentiary warrant for the assertion that is explicitly stated or is implicit in the narrative account. Such testing requires searching the entire corpus of information sources for any information that might bear on the working assertion. (A working assertion can be thought of as a tentative answer to a particular research question.)

To return to our hypothetical example of a study of student conceptions of dynamics, field notes of observations would be searched for any evidence that might confirm or disconfirm assertions about student conceptions. Interviews with students also would be reviewed with the same issue in mind, as would site documents, videotapes of classroom interaction, and any other possible sources of evidence that might bear on the issue of student conceptions of dynamics. If one knew that certain sources of evidence (e.g., site documents and a certain round of interviews) did not contain evidence about student conceptions of dynamics, these sources could be ignored in the search. However, any source with potential for data that bear on the assertion should be reviewed at least once.

The initial search for evidence needs to be exhaustive in order to ensure that crucial disconfirming evidence was not systematically ignored. Because there are many connected assertions in a final qualitative report, linked hierarchically across differing levels of generality and involving differing levels of inference, the corpus of research materials is searched repeatedly, considering each single assertion and each set of assertions in turn. In these searches, the researcher begins to employ verbal coding categories or some other means (such as colored markers highlighting portions of the field notes), thus indicating where relevant information is in the research corpus and what the content of those data are. As some assertions are disconfirmed in the search, they are revised, and the search is undertaken again with coding categories adjusted accordingly.

For example, for some students, a hard binary distinction between Aristotelian and Newtonian conceptions does not seem warranted in the data; those students seem neither Aristotelian nor Newtonian. Perhaps they are confused – one is not sure at first how to characterize these conceptions that do not fit easily into the dichotomy that had appeared at first glance. Having discovered during the search a three-way typology of student conceptions (Aristotelian, Newtonian, and "other/possibly confused"), the researcher goes back to the sources previously reviewed when the binary typology was in mind. The researcher then re-sorts the data to see if the three-way typology can contain all the instances that were identified.

Analytic Induction

This recursive process of reviewing evidence with an assertion in mind, revising the assertion in the light of the evidence, and then reviewing the evidence again has been called the "constant comparative" method of data identification and analysis (Glaser and Strauss 1967). I find that term misleading. The process of comparison is indeed recursive and progressive but not *constant*. The point is that one continues reviewing evidence until all relevant data have been identified and compared. One then goes on to another assertion or chain of assertions. I prefer the classic term *analytic induction* (Lindesmith 1947).

Gradually, through such a process of progressive problem solving, one finds that certain kinds of phenomena – actions, opinions, and kinds of social actors in the setting – covary in regular ways. One discovers post hoc various comparison groups, or sets of persons, actions, and opinions that are progressively regrouped as comparative analysis proceeds.

To return to our hypothetical example, one discovers that more of the students who retain Aristotelian conceptions of dynamics sat in the back of the room and that they also got average grades in English and Social Studies, in contrast to those students who sat in the front of the room, among whom was to be found the largest proportion (in the class as a whole) of students with Newtonian conceptions. More of the students who seemed confused asked for help from the teacher than did the students who held Aristotelian conceptions. When help was asked for, it tended to be done politely.

A number of the students who held Aristotelian conceptions were boys, and they appeared to be less polite in class overall than were the possibly confused students among whom, as a set, girls were overrepresented. As a set, these impolite students were also of lower socioeconomic status (and racial minority status was overrepresented in that set) in contrast to those who seemed confused or those who held Newtonian conceptions. Although most of the boys who held Aristotelian conceptions were impolite in class (and interviews with the Social Studies teachers revealed that these students, for the most part, were impolite in their classrooms as well), there were a few boys who were somewhat more polite to the physics teacher than others in their set who held Aristotelian conceptions. Those polite boys – some of whom were of white working-class background and some of whom were African-American – did not seek help from the teacher, but they also did not appear as impolite as the others in their set. Reanalysis of interviews with those students revealed that their conceptions were changing somewhat in a Newtonian direction, and that their responses appeared a bit like those in the "other" group, yet still distinct from them.

Looking now at all the students in the set of those whose conceptions were neither clearly Aristotelian nor Newtonian, it appears that some were increasingly more aware of the contradictions in the Aristotelian position and that what, at first analysis might have been seen as "confusion" in their conceptions, was better construed as a movement in the direction of Newtonian conceptions. This was true in this set of students more for those who sought help from the teacher, but it also was true for those students who did not seek help, yet were relatively polite in class. Were the polite students somehow more willing to take seriously what was being taught than were the impolite students? Were the polite students trying harder to learn? Were they less alienated from the Discourse of science than were the impolite students?

From such lines of questioning and reasoning, working recursively back and forth between hunches and data, one progressively arrives at new insights. The data show patterns of covariation across partially ordered sets of persons, actions, and opinions, considered together comparatively. (Usually the sets are *partially ordered* in that all members of a set are not identical and some features or properties of members of a set might be shared with members of another set, with proportions of different types of set members varying across sets.)

In our hypothetical example, "confusion" begins to be seen as a process of shifting conceptions and of changing identification with the Discourse, and the persistence of Aristotelian conceptions seems partly to be a matter of attitude on the part of students, especially male students of working-class and racial minority background. This appears to be not only a matter of willingness to seek help but, more fundamentally, a matter of student stance toward the teaching and the course content – toward the School Discourse – because some students who were polite but did not seek help tended to be moving toward the Newtonian conception (even though some students who were both polite and sought help seemed further along in a Newtonian direction than those who were polite and did not seek help). More of the polite students, however, considered together as a set, held conceptions that were moving more in a Newtonian direction than did most of the students who were impolite. However, there were some male students of upper-middle-class background, African-American and white, who held Aristotelian conceptions and were impolite, just as there were some white and African-American working-class students who held Newtonian conceptions. Thus the patterns of covariation between social background and academic performance were not simple, as the various sets in comparison groups were partially ordered.

The kind of reasoning sketched in our hypothetical example is not primarily a search for cause, as in the physical and biological sciences. It is a search for understanding. Which kinds of actions make sense, for which social actors, in which social situations? When one is alienated from a Discourse, how does it make sense to *work at* not learning what is taught? Goodenough (1981, pp. 54–57) observed that, because social life is so contingent, the kind of prediction that is possible in the hard sciences is not attempted in interpretive qualitative research. One does not attempt to predict that certain events will happen. One does want to be able to predict how people will react if a certain event happens – what sense they will make of it. Such understanding is the main aim of qualitative inquiry.

Frequency Counts and Discrepant Instances

Even though the analysis is "qualitative," it is apparent that the researcher must pay careful attention to frequency of occurrence, especially to relative frequency, in comparing different kinds of phenomena across differing comparison groups. It is necessary to count things and to make decisions carefully about what things to count and in which sets.

Usually in analysis that proceeds by analytic induction, the researcher identifies ways in which actions, opinions, or types of persons usually occur. These are the typical phenomena. One is also interested, however, in the atypical or those few discrepant cases whose closer analysis often can lead to new insights. Discrepant instances are not leftovers in analysis (e.g., working-class students who are not impolite or alienated in the physics classroom). Such instances and the circumstances in which they occur are scrutinized carefully. This is another reason why counting is important in qualitative research. It is essential, in exhaustive analysis of all instances of a field of phenomena, to identify the frequency of occurrence of all the types and subtypes, if one is to be able to distinguish between the typical and the atypical.

In a qualitative analysis, one wants to discover, through analytic induction, a few general assertions – pattern statements with a wide enough reach that they connect by threads, as it were, to sub-assertions, which ultimately are connected by threads to data bits across multiple sources in the total corpus of information sources. The most satisfactory analysis is one in which, by pulling a few threads at the top node of a *set of sets* of connected threads, more discrete bits of data are tugged on within the whole corpus of information sources than would have been by any other top-level nodes of threads (i.e., by alternate lines of interpretation and analysis).

Changing the Questions

What if, during the analytic process of progressive problem solving, it seems to the researcher that the questions posed at the outset of the study need to be revised? In an experimental study this would spell disaster. In a qualitative study it simply means that the post hoc analysis is working properly – discovering subtleties and contingencies that could not have been foreseen when the study was undertaken. This is why we do participant observational fieldwork: to discover what could not have been anticipated by the deductive reasoning of armchair theorizing. Often, even during fieldwork, as the result of partial or incipient analysis, it begins to seem that the research questions need to change. That represents progress. It is not a problem but an opportunity.

I am very suspicious of sustained participant observational research in which the initial research questions are not revised (in subtle shades of meaning or more fundamentally) by the time the study is concluded. In such studies, I suspect that the observer concentrated too hard on collecting information that confirmed initial assumptions, and then in data analysis overlooked all the contradictions and discrepant cases that might have been apparent had the researcher taken a more tentative and judicious stance with regard to evidence and conclusions. Analytic induction, when successful, teaches us fresh insights – something we could not have known before we started our inquiry.

Preparing Reports

Getting Started

Because qualitative data analysis never stops, experientially the researcher never feels ready to complete a report or often even to begin it. At such junctures, our intellectual integrity and sense of humility in contemplating the unknown can be liabilities if we let them immobilize us. It might help to remember, then, that qualitative reporting is inherently tentative. A qualitative research report can be thought of as a rendering or a construction. It is not the reality it attempts to represent.

As a text, the report consists of answers to the primary research questions of a study. It is an exercise in rhetoric. It makes an argument that, to be successful, must be both clear and persuasive. Clarity and coherence in reporting do not come on the first try; it is necessary to sketch and rewrite, drafting sections in nonlinear order and addressing diverse themes. Usually, one does not start writing the beginning of the report but rather writes drafts of the middle section first, which is the main descriptive account. Only then does one draft a concluding section and then, finally, one turns to writing the introductory section.

Writing a report involves making strategic decisions about what material to include, how to sequence it, and how to handle the inevitable tension between presenting evidence and overview. By presenting descriptive detail as evidence one convinces the reader but also risks confusing the reader with information overload. Conversely, presenting an overview maximizes clarity but risks failing to persuade the reader because of lack of evidence and lack of subtlety in reporting and analysis. Thus, there is a danger that one's report will be either thick and murky or thin and trivial. How to achieve a report that satisfies both the need for evidentiary warrant and for clarity is a difficult task.

Not Trying to Say Everything

Participant observational fieldwork amasses huge amounts of potential data. Only some of these become data through analysis, yet still more data are identified than could be included in any report. Thus, the process of sketching a series of first drafts most essentially involves deciding what *not* to include in them. Which of the many pertinent vignettes will not be told as illustrations? Which interview comments will not be presented? The same aphorism applies for reporting as for data collection and analysis: to draw is to leave things out.

Showing the Range and Frequency of Variation

In presenting the argument of a report, it is desirable to show not only the most typical or obvious patterns, but also the full range of variation and relative frequency of occurrence of data. The atypical, discrepant instances, as well as the more typical ones, need to be reported if the report is not to be one-dimensional and superficial.

In the most effective qualitative research reports, information about relative frequency is not simply presented to the reader as a matter of faith in the author's integrity and judgment, using fuzzy cover statements in narrative such as "usually" or "sometimes" or "most people." It is both possible and desirable in qualitative reporting to be specific about frequency through the display and interpretation of simple frequency tables.

There are three main types of text in a qualitative research report: particular description; general description; and orienting commentary. Each of these types, which are discussed below, can be thought of as containing subtypes.

Particular Description

This consists of narrative reporting of detailed evidence concerning the actions and beliefs of sets of persons in the setting that is being studied. Particular description can take the form of narrative vignettes that portray the actions of particular persons in specific events, or of quotes of what particular persons said in various interviews, or of quotes from particular site documents, or of a bit of demographic or historical information that applies specifically to a certain setting, such as a single classroom, household, or school building.

General Description

This consists of synoptic reporting that displays evidence for the existence of certain distinct patterns in the overall ecology of action and belief in the setting being studied (i.e., its overall social organization and culture). Particular description, through vignettes and quotes, presents pieces of the overall social ecology. General description shows patterns of *generalization within the case*. It provides an evidentiary warrant for the relative typicality or atypically of the specific vignettes and quotes that appear in the report and it portrays synoptically the setting as a sociocultural whole. General description also could include historical, economic, or demographic information that situates the local activities that were observed firsthand within the wider ecology of broader sociohistorical processes.

General description can take the form of frequency tables (the simpler the better), of analytic charts and typologies that identify key patterns of contrast in the setting, or of time lines and flowcharts that identify sequential patterns. General description is also done in words: "The teacher's approach stressed reasoning over memorization of facts." "Most of the students held an Aristotelian conception of dynamics, while some held a Newtonian conception and this did not change during the course of instruction."

This latter kind of general narrative reporting easily becomes hazy and it can represent unwarranted assertions about generalization within the case. Writing that "two thirds of the 24 students held an Aristotelian conception of dynamics while one third held a Newtonian conception" is a way to make "most" or "some" more specific and less hazy in narrative reporting. It is preferable, in saying that "the teacher's approach stressed reasoning over memorization of facts," to follow the generalization with an illustration of the kind of teaching that is meant. This illustration could be performed by presenting a narrative vignette of such teaching and then showing the relative frequency of that kind of teaching in a frequency table which shows the number of times that this kind of teaching was observed *and* which also displays the frequency of occurrence of all contrasting kinds of teaching that were observed. Combinations of general and particular description are much clearer substantively and are also more persuasive to the reader than presenting only general description, through which one sees patterns in a forest but learns nothing about the trees, or presenting only particular description, in which a tree might be exquisitely described but the reader has no sense of the forest.

Orienting Commentary

The third type of text in a narrative report is that of orienting comments. One subtype is the *interpretive or theoretical comment*, which might or might not invoke research literature: "That the Aristotelian conceptions of the students did not change is understandable because…" Another subtype of orienting comment is a summary of what has been said in a previous major section: "And so, we have seen that…" Yet another subtype of orienting comment is that of foreshadowing what is to come next in the text and of after-shadowing that which has just been presented. I think of these as "road signs." They let the reader know where the text is going and where it has just been.

Road sign commentary is necessary at each of the junctures in the text of the report: at the beginning of a new section consisting of multiple chapters; at the beginning and ending of each chapter; and at the beginning and ending of each new section within a chapter. We can think of this as *general commentary*. Even at the beginning and ending of each unit of particular description within a section of a chapter, some orienting comment is helpful. This can be thought of as *particular commentary*. Before and after each narrative vignette or interview quote, it is necessary to present specific orienting comments which (1) identify the substantive point to be illustrated by the particular example and (2) identify special details to which the reader should attend in the example.

Writing a Whole Section in a Report

This is analogous to stringing beads of varying sizes and shapes together into a necklace. The section would begin with general foreshadowing commentary that identifies an assertion – a substantive point, which will be illustrated in the section to come by means of units of specific description. In addition, the general commentary might outline the content to come (e.g., a sequence consisting of certain vignettes and interview quotes, then a discrepant instance, then information from a site document, and finally a frequency table which shows the typicality and atypicality of the various events and comments that were illustrated more specifically in the section).

After the general foreshadowing commentary, units of particular description follow. There might be two vignettes illustrating a typical kind of event, followed by two or three interview quotes that identify the points of view of actors in the events that were reported narratively (as noted above, before and after each of these units of particular description, brief specific commentary would be placed in order to keep the reader oriented). A vignette of a discrepant event might then be presented. Perhaps a few interview comments pertinent to the discrepant instance might follow or quotations from site documents might follow the discrepant instance. A frequency table or analytic chart, which showed how the various units of particular description fit into a more general pattern of evidence might then follow. Each successive unit of new information in the section would be preceded and followed by interpretive commentary. The section would be concluded with general commentary that reviewed the evidence and the issues that had just been presented.

Whether in a classic book-length monograph or in a journal article-length presentation, alternation of particular and general description and of particular and general orienting commentary is found in the best examples of qualitative research reporting. This feels assertive and it is. It is a new experience for beginning researchers, who might wish to try to let the story tell itself. Yet, unless the writer takes on a voice of executive commentary, actively leading the reader's attention through the text, the details of the report will not speak coherently to the reader.

Short Reports

In preparing an article-length report or an oral presentation that is limited to 15 or 20 min, there is a temptation to skip the particular description and try to tell the whole story of the study by means of general description. In my judgment, that is a mistake. It is better to narrow the range of coverage and state a single main point in an opening few paragraphs. Then I recommend selecting a few pertinent and vivid narrative vignettes and interview quotes to present, showing the typicality or atypicality of those instances by means of general description in a frequency table, framing each of the preceding units of descriptive reporting with orienting commentary, and concluding the article with a summary substantive discussion. Such a brief report, which sacrifices breadth for depth, will show clearly a few things and be much more effective than an attempt to "tell it all" in a voice of hazy, general description.

Toward Better Qualitative Research

Criticism of Qualitative Research from Within the Field

Currently, qualitative research faces serious criticism, not only from "hard science" advocates external to such research, but among qualitative researchers themselves. From insiders, there has been serious criticism of an overly authoritative voice in some forms of qualitative research, particularly ethnography (e.g., Clifford and Marcus 1986; Denzin 1996). To some extent, taking care to show clear evidence for assertions mitigates these criticisms. Other critics question the entire rationalist project of research. Critical social theory shows how ideological interests that are taken for granted and thus are invisible, or are deliberately obscured drive social research. Postmodern theorists challenge the possibility of a distinction between observer and observed, subject and object.

One consequence of this criticism has been a certain loss of nerve among qualitative researchers. A more positive consequence can be found in various attempts to bring the voices and perspectives of those studied into a more prominent place in research reports. Focus on meaning from the point of view of the social actor is a hallmark of ethnography. A way to improve the quality of ethnography involves taking more care that perspectives are not misunderstood because of faulty analysis or because of the re-voicing of opinions through editorial paraphrase. In some cases, however, the attempt to highlight the "voices" of those studied has led, in my judgment, to an overreliance on interview alone as a research approach. What makes this problematic, especially in a report, is that it can mask the editorial hand of the author. An interview quote is selected by an author and placed carefully in the report. It does not have the same epistemological status, in its written form, as a comment made directly by a speaker to a hearer in an actual speech situation. Simply relying on interview data, in other words, does not resolve the power/knowledge issues raised by the critics of naive realism in qualitative research reporting. The author still maintains tremendous executive power in the construction of a qualitative research report. This needs to be clear both to the author and to the audience.

In a sense, the author always will have more power than those who are portrayed by the author. With authorial authority comes professional responsibility and a sense of this has been heightened by those critics of qualitative research who have arisen from within that work's own ranks.

Another response to the criticism that traditional qualitative research invites abuses of authority by researchers (including those of self-deception in data identification and analysis) has been for researchers to try to redress the imbalance of power by sharing it more fully with those who are studied. Both participatory action research and practitioner research are attempts to address the power/ knowledge issues involved in social research (e.g., Anderson et al. 1994).

Possibilities

Despite their limits, qualitative methods can make important contributions to science education research. Qualitative research most essentially addresses issues of the literal and metaphoric meaning of actions to social actors, while it also documents those actions in the concrete details of their routine enactment. It is the most fundamentally constructivist research method available to us. It enables us to see and understand how, in the conduct of daily life, all persons are busy, active, and making sense.

Education as a social institution is heavily invested in the notion that only some are fully making sense and are "on task," and that others make less sense and are less active or less "motivated" (McDermott and Varenne 1995). That deep cultural belief, embedded in the workings of history which reproduces inequality in society, is manifested and reinforced so ubiquitously in the habitual conduct of teaching and learning in schools that it leads us, as educational researchers and as educational practitioners, to overlook the full diversity of ways of making sense and the full diversity of tasks – as defined by social actors – in which students and teachers are engaged. The sensitivity of qualitative research to nuances of activity and meaning in learning environments lends richness and depth to the study of the teaching and learning of science, and it is from that substantive perspective – perhaps more than the methods of research themselves – that future research in science education can benefit.

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Chapter 94
Analyzing Verbal Data: Principles, Methods, and Problems

Jay L. Lemke

Increasingly, the data of science education research are verbal data, including transcripts of classroom discourse, small-group dialogues, video, and interaction in online environments; talk-aloud protocols from reasoning and problem-solving tasks, students' written work, textbook passages, test items, and curriculum documents. Researchers wish to use data of these kinds to describe patterns of classroom and small-group interaction, development and change in students' use of technical language and concepts, and similarities and differences between school and community cultures, school science and professional science, the mandated curriculum and the delivered curriculum.

In this chapter, it is not possible to demonstrate actual state-of-the-art techniques of linguistic discourse analysis. My purpose here is to formulate the issues and choices of which researchers should be aware in adopting and adapting any method of analysis of verbal data for their own work. Along the way, I cite examples from my own published work and other sources which I personally find useful. Discourse analysis is a very large subject; its principles embody a theory of meaning-making that is nearly coextensive with a theory of human behavior and human culture (Lemke 1995a). Other useful introductions to discourse analysis and classroom discourse study include Cazden (2001), Christie (2002), Rymes (2009), Coulthard (1994), and Edwards and Westgate (1994).

In the sections that follow, I will begin by discussing the processes of data generation and contextualization, and then outline a general scheme for analyzing the three major dimensions of discursive meaning: semantic presentation, social orientation, and textual organization. I will end by briefly discussing issues of generalizability, interpretative bias, and educational usefulness of discourse analysis methods and their extension to multimedia and video analysis.

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How Researchers Construct Verbal Data

The language that people speak or write becomes research data only when we transpose it from the activity in which it originally functioned to the activity in which we are analyzing it. This displacement depends on such processes as task-construction, interviewing, transcription, and selection of materials, in which the researcher's efforts shape the data. Because linguistic and cultural meaning, which is what we are ultimately trying to analyze, is always highly context-dependent, researcher-controlled selection, presentation, and recontextualization of verbal data are critical determinants of its information content. Data are only analyzable to the extent that we have made them a part of our meaning-world and therefore also data about us.

Selection of discourse samples is not governed by random sampling. Discourse events do not represent a homogeneous population of isolates that can be sampled in the statistical sense. Although discourse events are unique, researchers aggregate them for particular purposes and by stated criteria. There are as many possible principles of aggregation as there are culturally meaningful dimensions of meaning for the kind of discourse being studied. The basis for aggregation ultimately is covariation: some change in the context or circumstances is associated with a systematic change in discourse features of interest to the study. Normally, because this cannot be known until the end of the study, it is wise to collect a larger and more diverse corpus of verbal data than ultimately will be used to support the analysis.

The basis of discourse analysis is comparison. If you are interested in covariation between text features and context features, you should not collect data only for the cases of interest, but also for cases that you believe will stand in contrast with them. For example, if you are interested in phenomena specific to women, to third-graders, to small-group discussions in laboratory settings, or to a particular curriculum topic, you also should collect potential comparison or reference data, in small amounts, for other genders, grades, settings, or topics.

Discourse analysis is also contextual. If you are interested in the language of any particular kind of event or text, you also should collect "around" it its probably relevant intertexts (see below). If you are studying how students write up their laboratory work, in addition to the texts that they write, you also will need data on how the same topics have been discussed in whole-class sessions, what the textbook says on the topic, any relevant written handouts, and perhaps also interviews with the teacher and the students.

All analysis is reductive. Information from the original data is discarded in the process of foregrounding the features of interest. Wise researchers preserve the original data in a form that can be reanalyzed or consulted again from different viewpoints, posing different questions. Spoken language never is analyzed directly. It is not even analyzed directly from audio or video recordings, but from written transcriptions. The process of transcription creates a new text whose relations to the original data are problematic. What is preserved? What is lost? What is changed? Just the change of medium from speech to writing alters our expectations and perceptions of language. What sounds perfectly sensible and coherent can look in transcription (any transcription) confused and disorganized. What passes by in speech so quickly as not to be noticed, or is replaced by the listener's expectations of what should have been said, is frozen and magnified in transcription. Normal spoken language is full of hesitations, repetitions, false starts, restarts, changes of grammatical construction in mid-utterance, nonstandard forms, compressions and elisions, etc. The tendency in transcription is to "clean it up," dismissing most of these features as irrelevant. Very often, some of them turn out not to be irrelevant at all. I recommend transcribing large portions of the corpus at the "lexical" level (preserving the sequence of whole, meaningful words and meaningful nonlexical vocalizations) for survey purposes, and then smaller portions at still more detailed levels for more intensive analysis.

The simplest transcriptions attempt to preserve information at the level of the word, but language only occasionally constructs meaning with single words. What matters is how the words are tied together, and that often includes intonation contours. Whether two phrases represent self-paraphrase or contrasting meanings often can be determined only from intonation. Transcription at the level of the word also erases information about emphasis, value-orientation, degree of certainty or doubt, attitude of surprise or expectability, irony, humor, emotional force, speaker identity, and speaker dialect or language background. Many of these features may be coded redundantly in the words as well, but some will not be. In addition, information about the timing of speech (length of pauses, simultaneous speech, sudden breaking-off of fluency, overlaps, etc.) is frequently important.

Written texts also carry considerable visual information such as handwriting forms, page layout, typography, and accompanying drawings and illustrations. This information, which can be very important for interpreting the meaning of verbal text, should not be lost to the analysis. Videotapes obviously contain a wealth of relevant visual information on gaze direction, facial expression, pointing and other gestures, contextual artifacts referred to in the verbal text, positional grouping, relative distances and directions, etc. Along with field notes, they help us to reconstruct the social situation or cultural activity type within which some meanings of the verbal language are very much more likely than others.

For useful discussions of transcription, see Erickson (1982), Ochs (1979), and Sacks et al. (1974). For the role of intonation, see Halliday (1967) and Brazil, Coulthard and Johns (1980). On visual information in text, see Kress and van Leeuwen (1996), Lemke (1998a), and Tufte (1983).

The Contexts of Verbal Data

Language is always used as part of a complex cultural activity. Verbal data make sense only in relation to this activity context and to other social events and texts with which we normally connect them, their intertexts. Meaning is not made with language alone. In speech, it is accompanied by gestural, postural, proxemic, situational, and paralinguistic information and, in writing, it is accompanied by choices in the visual coding of words and other graphical information. The meaning of any text or discourse event always depends on how we connect it to some (and not other) texts and events (on general intertextuality, see Lemke 1993).

What the teacher is saying now makes sense in part in relation to what she said 10 min ago or yesterday, what we read in the book, the question that you missed on the last quiz, etc. It also makes sense differently depending on whether she is reviewing or introducing new material, whether it is addressed to one student or to the whole class, and whether it relates to a diagram on the board or not. What a student says can make meaning in relation to the past history of his dialogue with this teacher, the group dynamics of the class, his boredom with the topic, and his personal relations with other students.

There are many schemes for systematizing the probably relevant contextual factors of a text or discourse event (e.g., Erickson and Shultz 1981), including the participants and their social and physical relationships, material objects and semiotic representations in the immediate physical environment, the cultural definition of the activity type or situation and its roles and expectations, and the channel or medium of communication. More important than such lists are (1) the principle that the discourse itself can create a context, make a part of the environment newly relevant, or even change its meaning, and (2) that the context is itself a kind of text that must be "read" from the viewpoint of the verbal discourse. Verbal data, including particularly written or printed texts, always make sense in relation to (1) a context of production, or the circumstances in which they were written or spoken, and (2) a context of use, or the circumstances in which they are read or heard. For written texts, these two can be very different (see Lemke 1989).

Texts and discourse data index or point to relevant contexts in a variety of ways (e.g., Wortham 2005). The simplest is through deictic forms such as this, that, the other, over there, now, as we saw before, and mine. These forms indicate to the listener that meaning must be made jointly with the textual and the relevant contextual information. In addition to the context of situation, there is also more generally the context of culture (e.g., Halliday and Hasan 1989) that is indexed by a text. Much of this is a presupposition of familiarity with other texts, cultural norms, genre conventions (see below), etc. in a particular community.

Nonverbal signs, which co-occur with spoken language, especially "body language" signs form, with speech, a single integrated meaning-making and interpersonal communication system. Very little really is known yet on how the different channels of this system modulate each other's meaning effects (see Kendon 1990).

The Dimensions of Verbal Meaning

Language in use always creates three interdependent kinds of social and cultural meaning. It constructs social relationships among participants and points of view; it creates verbal presentations of events, activities, and relationships other than itself; and it construes relations of parts to wholes within its own text and between itself and its contexts.

Presentational meaning is the most familiar and most studied. This aspect of meaning often is referred to as representational, propositional, ideational, experiential, or thematic content. This is the function of language for presenting states of affairs (i.e., for saying what is going on). It presents processes, activities and relationships, as well as the participants in these processes, and attendant circumstances of time, place, manner, means, etc. It defines entities, classifies them, ascribes attributes to them and counts them. In relation to these semantic functions, its grammar has been described usefully by Halliday (1985). My own work on thematic patterns or formations (e.g., Lemke 1995b) applies Halliday's analysis to textual and intertextual patterns in discourse (see below).

Orientational meaning can be even more fundamental developmentally. This aspect of meaning, also called interpersonal or attitudinal, constructs our social, evaluative, and affective stance toward the thematic content of our discourse, toward real and potential addressees and interlocutors, and toward alternative viewpoints. It includes: the language of formality/intimacy, status and power relationships, and role relationships; speech acts, such as promising/threatening, joking, insulting, pleading, requesting/demanding, and offering; evaluative stances toward the warrantability, normality, normativity, desirability, seriousness, etc. of thematic content; construction of affective states; and construction of alliance, opposition, etc. between one theory or viewpoint about a matter and others available in the community. Useful sources on these aspects of orientational meaning are available in many sources (e.g., Lemke 1998b).

Organizational meaning is not perceived always in our culture as meaning, but analysis shows that it is an integral member of the team, functioning together with, and indeed enabling, the other two. Organizational meaning includes the ways in which language creates wholes and parts, how it tells us which words go with which other ones, which phrases and sentences go with which others and how, and generally how a coherent text distinguishes itself from a random sequence of sentences, phrases or words. Organizational meaning in language generally is created through simultaneous use of the two complementary principles of (1) constituency structure, in which a larger meaning unit is made up directly of contiguous smaller units and (2) cohesive structure, or "texture," in which chains of semantic relationships unite units which could be scattered through the text. Constituency structures can be interrupted and resume, and are at least in principle "completable." Cohesion chains, which have neither of these properties, are built on a variety of chain-membership principles, all of which specify a particular kind of relation of meaning among the items (e.g., synonyms, members of a common class, contrast, agent-action, action-means, attribute-item).

Constituency structures (genres, genre stages, rhetorical formations, adjacency structures, clause-complexes, clauses, phrases, groups, etc.) create local meaning relationships among items, which also generally belong to cohesion chains, and they provide one means for creating new bases for cohesive relations. Real texts, especially extended complex discourses, often change genre types or other constituency strategies many times, creating subunits within a text. Cohesive relationships provide a principal means of creating semantic continuity across these segmental boundaries within a text.

Some forms of meaning depend about equally on two of these three semantic functions, so that, for example, logical relationships (because; if … then) normally function both presentationally and organizationally. For useful discussions of organizational meaning, see Halliday (1978), Halliday and Hasan (1989), Hasan (1984), Lemke (1995b), Martin (1992), and Matthiessen (1992).

Semantic Content Analysis

How can we characterize what a text says about its topics, or even what its topics are, better or more concisely than the text does itself? This is possible only to the extent that the text repeats the same basic semantic patterns, makes the same basic kinds of connections among the same basic processes and entities again and again. In our culture and most other cultures, not only do we repeat these thematic patterns, or formations, again and again in each text, merely embroidering on the details, we also do so from one text or discourse event to another.

This is especially true in the sciences and other academic subjects for which there are accepted, canonical ways of talking about topics. Most textbooks tell you much the same thing about atoms, alternating current or Mendelian inheritance. However they present it, we expect that what teachers say about these topics will contain this same information, and that, when students reason, talk, write, or take tests, their discourse will fit these patterns too (at least eventually). The common techniques of concept mapping are based on our ability consciously to abstract the essential meaning relations among key terms in scientific discourse. Discourse analysis, however, can produce the same patterns, and be more semantically explicit about their content, from free-form classroom or small-group talk, or from written materials of any kind. This means that these direct uses of scientific concepts directly can be sampled, assessed, and compared. The basic technique for doing this is described in Lemke (1990) and its linguistic basis and extensions are discussed more fully in Lemke (1995b).

Other forms of modern semantic content analysis are statistical, corpus-based, and collocational. Given the present limitations of computer analysis of natural language texts, these analyses are based on forms rather than meanings. They can tell you a text's frequency distributions and, more importantly, the joint distributions for pairs (or n-tuples) of words or fixed phrases. They cannot tell whether a given word is used with the relevant meaning in which you are interested in any particular instance. Thematic analysis, correspondingly, must be done by hand, but it enables you to see that the same concept or relationship can be expressed by many different verbal forms and grammatical constructions, and to exclude cases for which the form is right but the meaning in context is not. To do thematic analysis properly, you need to be familiar with both the subject matter content of the discourse or text, and with the semantics of at least basic lexical and grammatical relations at the level of Halliday (1985) and Hasan (1984).

Rhetorical Interaction Analysis

All language in use, whether spoken or written, is explicitly or implicitly dialogical; that is, it is addressed to someone and it addresses them, and its own thematic content, from some point of view. It does rhetorical and social work, producing role relationships between author–speaker and reader–hearer with degrees of formality and intimacy, authority and power, discourse rights and obligations. It creates a world of value orientations, defining what is taken to be true or likely, good or desirable, important or obligatory.

Some useful questions to guide rhetorical analysis include: What are these people trying to accomplish here? What are they doing to or for one another? How is the talk ratifying or changing their relationships? How is it moving the activity along? How is it telling me what the speaker/writer's viewpoint is? What is it assuming about my viewpoint and other viewpoints? How does it situate itself in relation to these other viewpoints? What is its stance toward its own thematic content, regarding its truth or probability, desirability, frequency or usuality, importance, surprisingness, seriousness, naturalness, or necessity?

Rhetorical analysis needs to be done at each organizational level of the text. What is the function of the choice of genre as a whole (see below), of each stage in the unfolding of the genre, of the local rhetorical formation and each move within it, of the sequencing of formations and topics, of various interruptions, digressions, and the timing of returns, of grammatical constructions, of word choices, of pauses, intonations, and marked pronunciations?

Those features of a rhetorical analysis that rely, as thematic analysis does, on patterns that commonly are found in many texts, tend to be agreed on by different analysts. But rhetorical analysis must deal with situations unique to the text at hand much more often, and these are more ambiguous and subject to different interpretations. In these cases, the multiple forms of evidence needed to support interpretations include word choice, intonation, grammatical choice, and contextual information about the situation or activity. Even the participants in a discourse could disagree about the rhetorical meanings of particular features, or change their minds in retrospect or with additional information. The "intention" of the speaker, as revealed in a retrospective interview, is just one more piece of data; it does not settle the question of what a feature meant for any participant at the time. Evidence of how participants followed up the appearance of the feature might be more persuasive.

In and of themselves, discourse forms do not "have" meanings; rather, they have a range of potential meanings. Words, phrases and sentences are tools that we deploy in complex contexts to make more specific meanings, to narrow the potential range of possible meanings down to those reasonably or typically consistent with the rest of the context. Even in context, at a moment, an utterance or phrase might not have a completely definite meaning. It could still express a range of possible meanings, differently interpretable by different participants or readers. This is very often the case at the point where it occurs. The context needed to specify its meaning very often at least partly follows its occurrence. So it might seem to have a more definite meaning retrospectively than it has instantaneously. In fact, depending on what follows, its meaning as participants react to it can be changed radically by what follows (retrospective recontextualization). Analyzing a text to see what is happening to meanings moment-to-moment yields a dynamical analysis; when all is said and done, the overall net retrospective meaning yields the synoptic analysis.

For a variety of good examples of rhetorical or speech act analysis, see Gee (2007), Green and Harker (1988), Lemke (1990), Mann and Thompson (1988), and Wortham (2005). For discussions of evaluative and affective meaning, see Lemke (1998b) and Martin and White (2007). For viewpoint analysis, see discussions of heteroglossia in Bakhtin (1935) and Lemke (1995a). For discussions of social voices, see Wertsch (1991). For dynamic and synoptic analysis, see Lemke (1991) and Martin (1992).

Structural-Textural Analysis

Verbal data have social meaningfulness only as text, not as collections of isolated words or phrases (except statistically). How does a coherent, cohesive text differ from a random collection of grammatical sentences? How are texts and discourse events unified and subdivided into wholes and parts? How can we define the boundaries of a unit or episode of a text or verbal interaction? What binds the units of a text together?

Structural analysis of texts needs to be both "top-down" and "bottom-up," that is, it needs consistently to reconcile analyses that begin from the smallest units of meaning (normally phrases and clauses) and look for how these aggregate together into larger units, with analyses that begin from the largest units (normally activities and episodes or genres and their stages) and look for how these are composed of functional constituents. The largest unit of analysis for a spoken discourse text is the socially recognized activity-type in which the discourse is playing a functional part, or the smallest episode or subunit of that activity which contains the entire discourse event. A classroom lesson is a typical activity-type of this kind. An episode of Going-Over-Homework or Working-in-Groups can form the more immediate context. The largest unit for a written text is normally the whole genre of which it is an instance.

A genre is a text-type specified by identifying a common structure of functional units (obligatory and optional) that is repeated again and again from text to text. A speech genre generally is a highly specific activity-type accomplished mainly by verbal means. The term genre is used more often for types of written texts because they are more structurally standardized in our culture. A genre has a constituency structure in which each constituent plays a functional role in the whole and has specific functional meaning relations to the other constituents on its own level. The largest units often are called stages, and they can be composed of smaller units, and these of still smaller ones, etc. Each constituent at each level of analysis should be defined in a way that is unique to the genre. A science laboratory report, as a written genre, might have major stages such as Title, Author, Class, Statement of Problem, Description of Apparatus, Description of Procedures, Record of Observations, Analysis of Data, Conclusions, etc.

Some constituents of some genres have an intermediate level of organization between genre-specific units and grammatical ones. These often are called rhetorical structures or formations (e.g., Lemke 1988). They are found in essentially the same form in many different genres, but they have an internal functional or rhetorical structure in addition to the structure of their grammatical units. The most famous example in classroom discourse analysis is the I-R-E structure, typically realized as Teacher Question, Student Answer, Teacher Evaluation (see Lemke 1990). More common and widespread examples include the simple Question–Answer adjacency pair or other structures such as Examples–Generalization, Event–Consequences, Syllogisms, etc.

Below the level of smallest genre-specific units and the moves within a rhetorical formation, we find the level of grammatical structure. Analysts should be aware that there are multiple simultaneous grammatical units structuring the same set of words, and that some of these can depend on intonation as well as word sequence. The boundaries of these different units are not necessarily the same.

The classic problem of textual structure is segmentation. Can a text be divided definitively at word boundaries into its constituent units at any level of analysis? The answer is: only sometimes. The same word can function as an element in different units, for different functions and on different scales. The boundary, particularly of a large, high-ranking unit (e.g., genre stage, rhetorical move) can be indeterminate in terms of lower-level grammatical or word units because it is defined by several simultaneous criteria, each of which results in drawing the boundary in a slightly different place in the text. As a general rule, units of meaning can have fuzzy boundaries in terms of units of form (or even in terms of units of meaning at a different level of analysis).

Some texts are more rigidly structured than others. Some maintain, repeat, and complete particular genre patterns or rhetorical formations more consistently than others. Many texts frequently shift genre pattern or rhetorical strategy, with or without completion of those already started. Conversational discourse is notorious in this respect, as are written texts by young writers who have not learned yet the genre conventions and borrow from the norms of conversational organization. The way in which such texts maintain their coherence largely is by topic continuity or, more generally, by maintaining cohesion chains, whose members have no consistent structural–functional relations. If a structure looks like A–B–C–D, a chain looks like A–A–A–A. Chains can be of many kinds. Lexical chains consist of words each of which can be the same word, have the same meaning in context, refer to the same referent, belong to the same semantic domain, etc. A short lexical chain can be accidental; a long one rarely is.

Larger units than words can form chains or strands. A structural pattern can be repeated (cf. rhetorical parallelism): A–B–C–D, A–B–C–D, A–B–C–D, etc. More commonly, and very importantly, a thematic pattern can be repeated, and varied, at different levels of abstraction (see Lemke 1995b for an extended analysis). Chains also normally interact with one another; that is, in each instance from two different chains, there is the same structural relation each time between the member of one chain and the corresponding member of the other. Not just chains of individual lexical items, but chains of whole thematic formations, can interact. It can take only a clause or nominal group (noun phrase) structure to tie members of two lexical chains together, but it can take much larger and more complex grammatical or rhetorical structures to do this between large thematic formations (see Lemke 1995b).

For further discussions of genre analysis, see Bazerman (1988), Hasan (1989), Martin (1992), Lemke (1991), and Swales (1990). For cohesive organization, see Halliday and Hasan (1976), Hasan (1984), and Lemke (1995b).

Case Studies and the Problem of Generalizability

How can verbal data and discourse analysis be used in studies of individual episodes and lessons, classrooms, and small groups? What is the value of such studies and how can we determine the generalizability of their findings?

Discourse analysis studies are often best when they examine a particular community in-depth. Discourse analysis produces its greatest insights when rich contextual information can be factored into the analysis of each text or episode. For this reason, longitudinal designs or case studies are well suited for discourse analysis methods. Here we may learn a great deal about a particular class, seeing repeated patterns within the data and a variety of strategies that create variations on those patterns.

It is not true that science should be only about generalized properties of classes of phenomena and not about unique properties of individual instances. The balance between these two approaches must be struck differently depending on the nature of the phenomena. Electrons seem to have no individuality that matters; biological systems do, but a great deal of their structure and behavior remains constant for a species or variety. Developmental phenomena show a wide range of individual pathways. Human communities and cultures are often more interesting for what is unique to them than for what they all have in common. Moreover, one of the important properties of any class is precisely the specification of how the members of the class differ from one another.

Discourse analysis will not tell us a lot about how all classrooms or all science writing is alike (though it will tell us something), but it provides us with the tools to analyze and understand more exactly what is going on in any particular discourse or text we wish to analyze. That is as much as any theory really does for us in practice.

Protocol Analysis and the Problem of Interpretation

When task activities differ significantly from normal cultural routines, how will cultural patterns of language use be distinguishable from idiosyncratic constructions? What is the object of study that we construct from such data?

One important form of verbal data is generated when researchers construct special task activities that differ significantly from normal cultural routines. This follows the traditions of the natural sciences in devising tasks meant to reveal particular aspects of phenomena, but it encounters the risk (minimal for electrons and molecules, but already significant for organisms) that behavior under task conditions differs in important and unknown ways from that in normal routines. The essential context-sensitivity of meaning-based phenomena (meaning is selective contextualization) strongly suggests that, if we are interested in a classroom phenomenon, we should study it in situ. If we supplement this with artificial tasks, it is then necessary to establish empirically that the differences between the task context and the natural context do not alter the phenomena of interest, or to identify in exactly what ways they do alter them.

Current models of situated cognition call into question the assumption that meaning-making processes can be assumed independent of local contexts, or even that "cognition" is a process in a system limited to the organism itself (as opposed to one that includes the organism's tools and the elements of the environment with which it interacts, cf. Lemke 1997). Discourse analysis assumes that the resources and strategies (lexis and grammar, rhetorical formations, typical cultural narratives, genres, thematic formations, etc.) used in producing discourse events and texts are characteristics of a community, rather than unique to an event in that community. They are part of its general cultural resources (and so differ from culture to culture and from one community or subcommunity to another). But what it means to have a culture is that we preferentially deploy some of these resources in some contexts rather than in others; how we use the resources is essentially context-dependent.

The analysis of the covariation between situational features and the lexical and grammatical resources typically deployed in them is the subject of register theory (e.g., Halliday 1978), which can also be adapted to analyze the clause-to-clause shifts in meaning that take place through a text (phasal analysis; Malcolm 1985).

Comparative Studies and the Problem of Cultural Bias

When we use discourse analysis and verbal data to compare males with females, middle with lower class subjects, widely differing age groups, different cultural and linguistic groups, and school practices with home, community, or professional practices, we necessarily introduce our own viewpoint, which invariably is closer to that of one of the categories compared than to the others.

Discourse data are not only sensitive to the context of immediate task and situation; they also are sensitive to the wider context of cultural norms and assumptions, knowledge, beliefs, and values. The analysis of discourse data or its interpretation is itself just more discourse from the point of view of the researcher's community. Our research communities and their historical traditions emphatically are not balanced equally by gender, age, social class, or ethnic culture. Even studies which strive mightily for evenhandedness and neutrality of description necessarily are read by other researchers who will project their own values regarding what is better and what is worse onto what were originally mere descriptions of difference. In many other studies, even the questions which are asked of the data are asked from a narrow range of human viewpoints.

Discourse analysis is always interpretation and it is just as viewpoint-dependent as any other instance of discourse. The canonical procedures of discourse analysis briefly sketched here provide a means for different analysts to compare systematically the many interdependent grounds of their respective interpretations. Whether they reach consensus or not is probably less important than that procedures be clear enough for others to enter into the discussion on common ground. These procedures, of course, are themselves the product of a relatively narrow range of human viewpoints. We can hope that this range will widen as the field of discourse analysis, and our own society, mature toward more inclusiveness and respect for the value of diversity.

Video and Multimedia

Video data today come not just from classrooms and face-to-face group interactions, but also from screen-captures of learners working in online or more generally computer-mediated virtual environments. It may also be video created by students and teachers. This video often contains verbal data, but its interpretation may depend critically on how it is mutually contextualized with visual signs, movements, actions, etc. recorded in the video. Many of the techniques discussed here apply to video and more generally to multimedia or multimodal data. In particular the principles in Lemke (1998a) regarding how cross-contextualization influences meaning between verbal and visual elements are useful.

For a general discussion of video analysis for education research see Goldman et al. (2007). For examples of the analysis of multimedia data relevant to science education see Lemke (2002).

Conclusion

The methods of discourse analysis of verbal data can be used to compare curriculum documents, textbooks, and tests with classroom dialogue, teacher discourse, student writing, etc. They make possible rich descriptions of the lived curriculum, its relation to official curriculum plans, and to the web of intertextuality among all the spoken and written language in which education is framed. They also make it possible to analyze how individual students use scientific language and concepts in a variety of situations, and to make this a basis for evaluative assessments. They will become even more important as components of future interactive virtual learning environments, which will enable students to explore new information worlds more successfully. Researchers of the next generation will help to determine whether discourse analysis methods will be used to empower students in the new century, or to control them more strictly.

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Chapter 95
Employing the Bricolage as Critical Research in Science Education

Shirley R. Steinberg and Joe L. Kincheloe

Too often, discussions of critical research lapse into both historical discussions of the Frankfurt School of critical theory, and in lengthy analyses of distinctions between varieties of critical social theory. While such discussions are important, this chapter discusses these critical traditions in terms of their implications for research and teaching in science education. Where possible, attention focuses on practical implications of the critical conversation for those interested in progressive pedagogy and knowledge production in science education. Because the analysis of a critical form of science education research is conceptually inseparable from the critical critique of modernist science, this relationship is considered throughout the chapter. The research bricolage is presented in light of viewing ways in which different epistemological research "methodologies" can be employed when doing science education research.

The chapter is structured into three sections that focus on (1) a clarification of the nature of critical research, (2) the critical discussion of modernity, including the importance of cultural studies, (3) methodologies of critical research, employing the bricolage and their implications for science education researchers.

The Critical Domain

The "critical" aspect of critical research assumes that the inequalities of contemporary society need to be addressed and that the world would be a better place if such unjust realities could be changed. Thus, we explore the world, science included, for the purpose of exposing this injustice, developing practical ways to change it, and

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identifying sites and strategies by which transformation can be accomplished. Although the notion is simple, the process of accomplishing it is disconcertingly complex. Critical research needs to meet five requirements:

1. It rejects positivistic notions of rationality, objectivity, and truth. Positivist rationality involves the assumption that human beings control their destinies through the application of social techniques derived from empirical science. Through scientific reason, educators, social workers, psychologists, and other cultural workers can make use of sciences of control (cybernetics) to produce flexible, efficient, and obedient citizens.
2. It attains an awareness of its own value commitments and those of others, as well as the values promoted by dominant culture. One of the main concerns of critical action research involves the exposure of the relationship between personal values and practice. Critical research makes its value assumptions known to its consumers (e.g., that science should be employed for peaceful, socially just, and democratic purposes).
3. It cultivates an awareness of the social and political construction of professional consciousness. Critical research understands that academic researchers are socialized into professional cultures with mores and folkways. It insists on making public these tacit customs.
4. It attempts to uncover aspects of the dominant social order that undermine the pursuit of critical egalitarian and democratic goals. Critical research attempts to expose the specific *modus operandi* which power deploys to crush critical objectives in the larger effort to protect its own privileges (e.g., the ways in which corporate and governmental financial support of scientific research often shape the questions which scientists ask and the answers they provide).
5. It is always conceived in relation to practice. Critical research is never disinterested and it exists to improve practice (see Kincheloe and Berry 2004). The employment of a bricolage allows a socially just and polysemic approach in creating thicker textual readings of research.

Oppositional Traditions

Our description of critical research draws upon emergent schools of social theory. First, Frankfurt School critical theory (a discourse of social transformation) is associated with the work of Max Horkheimer, Theodor Adorno, and Herbert Marcuse. Second, Michel Foucault's genealogy (the reconstitution of ostensibly mundane historical memories that are dangerous to the dominant way of understanding the world) attempts to understand social practices even when the researcher has been shaped by the social practices). Third, the practice of poststructuralist deconstruction (a method of reading, an interpretive strategy, and a philosophical position that views the world as full of texts to be decoded and explored for unintended meanings) is associated with Jacques Derrida. Fourth, the critical currents (ways of understanding the world that challenge the certainty of modernist science with its linear, cause–effect forms of logic and rationality) associated with critical cultural studies and critical pedagogy.

Using these critical theories in combination with the pragmatic tradition out of which John Dewey's progressive education developed, an oppositional research impulse can emerge. Dewey wrote in the early twentieth century about a form of research that consciously challenged the technicist desire for certainty. Our notion of critical research is nurtured by Dewey's notion, as it undercuts mainstream science's comfort with taken-for-granted sociocultural and educational patterns. In a dominant culture that has not always valued self-reflection on the part of its teacher professionals, critical research becomes a de facto oppositional activity as it pushes professionals in a variety of fields to reconsider their assumptions (Greene 1988). Kincheloe and Berry (2004) argue that critical forms of inquiry do not claim truth in a way that is unaware of the metaphors that guide their meaning. Indeed, such critical research forms do not conceive knowledge as simply something to be discovered. Information produced by critical inquiry, a self-conscious social text is produced by a plethora of mutually informing contexts. This concern for context becomes a defining feature of critical research, as practitioners focus their effort on conceiving new ways of contextualizing scientific knowledge, teaching, and students.

Identifying Power and Oppression: Research for Empowerment

Because critical theory is grounded on the recognition of the ways in which power oppresses, the forces of oppression have to be identified (Kincheloe and Steinberg 2008). In the context of critical research in science education, one of the first places where critical inquirers might look for oppression is positivist (or modernist) science itself. Critical observers have maintained that prediction and control of external phenomena are presupposed in the language of science as well as mathematics and statistics. The external phenomena in question involve the control of nature to serve human ends (Aronowitz 1988). *Modernist science is committed to expansionism or growth*, which are terms that frequently are confused with progress. Expansionism of this type demands that individuals be programmed for the progress-oriented agenda even when it conflicts with their best interests or the best interests of the community. *Modernist science is committed to the production of profit and measurement*. Too often, ideas, commodities, and people themselves are evaluated in light of their relation to profits. The obsession with instrumental rationality and measurement defines the goals and outcomes of traditional science research. When individuals engage in actions that are contrary to the interests of profit making, science tends to reshape their behavior by labeling it as deviant or pathological. Finally, modernist science is committed to the preservation of bureaucratic structures, which are maintained by "scientifically proven" measurements. Science serves as the force that processes people in relation to the smooth functioning needs of bureaucracies. It is the bureaucratic need, not the human need, which takes precedence when a conflict arises.

In a democratic context, teacher researchers decide what needs to be learned and discovered in their classes, how such experiences might contribute to sophisticated thinking necessary to democratic citizenship, how to help children learn it, and how such learning might then be assessed. In a positivistic system we know that the quality of our teaching, our research, and student learning will be tested and measured even if it is never clearly specified what exactly constitutes the purpose of testing. Even if the tests serve to fragment, narrow, deflect, and trivialize the curriculum, we still must use them because accurate scientific measurement takes precedence over such curricular considerations. This positivistic obsession with measurement, exemplified by the high-stakes testing, and the discourse of top-down standards, forces us to assume for the sake of testing efficiency that there is a specific body of knowledge to be learned, and there are correct methods for teaching and learning it.

Such an assumption forces us to unquestioningly accept the validity of the specific body of knowledge to be learned and that such truth belongs in our classrooms. Teachers and educational researchers need not trouble themselves with inquiry about the constituent interests of this knowledge. Educational researchers need only concern themselves with empirical investigations of how best to teach this information. If we manipulate this variable in this specific way, do students acquire more or less of the knowledge? Thus, many would argue, educational issues in this positivistic framework are reduced to technical issues. Questions of ends or purposes are subservient to questions of means or techniques. Critical theorists have labeled this tendency "instrumental rationality." Advocates of critical qualitative approaches to educational research argue that the purpose of educational activity must always be an integral aspect of the research process (Kincheloe and Berry 2004).

Science is a force of domination not because of its intrinsic truthfulness, but because of the social authority (power) that it brings with it. Expressions such as "scientists contend," "science has proven," and "the test results tell us" signify a power difficult to counter. Critical observers are quick to warn their audiences not to perceive this "science-as-power" concept too simplistically. The way in which science exerts its power is quite subtle and rarely takes place without eliciting resistance. Men and women are not cultural dupes who are manipulated by "grand conspirators" in unspecified "high places." If people were merely cultural dupes, how could we teach them anything? We could possibly use some manipulative behavioral conditioning, but any respectful, reflective progressive pedagogy would not work with such dupes. At the same time, if we were not occasionally duped by power interests, there would be no need to promote our self-awareness and sense of agency. The development of such a consciousness would empower us to regain control of our lives from those who would use us to serve interests other than our own (Grossberg 1994). Thus, the power of science to shape and control should be analyzed by informed researchers who refuse to allow grand ideological pronouncements to substitute for specific inquiry.

An example is the way in which an unexamined scientism subverts our attempts at democracy. With the increase of environmental hazards resulting from scientific "progress," citizens sometimes seek to legitimate a "totalitarianism of hazard prevention" (Beck 1992, p. 80). In the attempt to prevent something bad (environmental side effects), something worse (suspension of democratic principles) is produced. In this context, the population is divided along a new set of axes – expert versus nonexpert, or those who possess the language and methodology of modernist scientific research versus those who do not. The mass of nonexperts, the experts maintain, must be provided with technical details that will condition them to respect the magic of the scientific elite. The cultivation of such respect is tantamount to a pacification program designed to quell public protest, criticism, or resistance (i.e., to disempower and depoliticize). Use of media has been employed to create populist narratives geared to "simplifying" scientific research. We have seen the global warming debate reduced to Al Gore's sophisticated PowerPoint documentary and, naturally, a backlash politically funded and fought on partisan grounds. Indeed, in the past decade, scientific research and education has found a lay audience in the media, creating a pseudo-informed population that reacts knee jerk on the blog/documentary/tweet/best seller of the day.

Such an example of anti-democratic scientism highlights the empowerment impulse in critical research. Inquiry that aspires to critical status is connected to the larger effort to confront various kinds of antidemocratic impulses, especially those embedded in the discourse of science. Such research thus becomes a transformative effort unembarrassed by the label "political" and unafraid to consummate a relationship with an emancipatory consciousness. Emancipatory consciousness involves the attempt to free oneself from the tacit controls of racial, class-based, and gendered discourses and lived practices. Horkheimer (1972) succinctly argued that critical research has never been satisfied with merely increasing the knowledge base. Therefore, a critical rendition of science education research attempts not simply to understand the dynamics of science and pedagogy and the interesting ways in which they intersect. Also, critical science education research attempts to change science and pedagogy by moving them into the emancipatory domain. Critical science education researchers use their work to empower science educators to construct their practice along well-analyzed moral, ethical, and political principles.

Science teachers who enter schools with such understandings and research abilities are prepared to make a cognitive leap. Indeed, the stage has been set to move to postformal thinking (Kincheloe 1995). As critical researchers with a vision of "what could be" and a mechanism for uncovering "what is," these teachers see the sociopolitical contradictions of both science and schools in a concrete manner. Such recognitions encourage reflection as they induce teachers to understand how these sociopolitical distortions tacitly have worked to shape their worldviews and self-perceptions. With a deeper understanding of such processes, practitioners recognize the ways in which power operates to create oppressive conditions for some groups and privilege for others. Thus, critical research opens new ways of knowing that transcend formal analysis (e.g., Steinberg 2006).

Theoretically Grounding Critical Research: The Rise of the Critique of Positivist Knowledge Production

Positivist research methods and modernist science itself have been called into question over the power of technology or the dispassionate goals of science. We have begun to doubt the value of many of the social and technological changes made possible by disinterested science. We associate positivism with modernism in a social theoretical description.

The Birth of Modernism/Modernity: Parenting Positivists

Modernism was born with the realization that the Western medieval way of seeing was no longer adequate. The Black Death, for example, had swept across Europe in the fourteenth century killing at least a quarter of the population and changing the social order of the West forever. Every technique derived from the medieval ways of understanding the world was used to help control the plagues. Prayer, mysticism, scapegoating, and magic had no effect on the disease. When a society is unable to understand or solve a major problem, which challenges its existence, its organization of reality collapses or a new one develops. Under the pressure of the Black Death, Western society began to develop a new way of seeing. This new impulse, that would lay the foundation of Western modernism, enabled the society to understand and control the outside environment, especially matter and energy (Bohm and Peat 1987). Modernity refers to the era, that time period beginning between 1650 and 1800 coinciding with the Enlightenment and the birth of modernist science and lasting until sometime after World War II. Modernism refers to a way of understanding the world produced by Enlightenment thinkers and employing a scientific methodology and the concept of rationality, this mode of thinking, especially in regards to science is also referred to as positivism – the unadulterated belief that science is provable, that truth is found only through science, and that measurement assures this proof and truth. The foundation of the modernist science emerging in the 1600s and 1700s rested on the separation of the knower and the known, which is a cardinal tenet of the Cartesian–Newtonian (e.g., Rene Descartes and Sir Isaac Newton) way of organizing the world. Rene Descartes' analytical method of reasoning, often termed "reductionism," asserted that complex phenomena can best be appreciated by reducing them to their constituent parts and then piecing these elements together according to causal laws (Mahoney and Lyddon 1988). All of this took place within Descartes' separation of the mind and matter. Known as the Cartesian dualism, human experience was divided into two distinct realms: an internal world of sensation; and an objective world composed of natural phenomena. Drawing on the dualism, scientists asserted that the laws of physical and social systems could be uncovered objectively; the systems operated apart from human perception, with no connection to the act of perceiving. Descartes theorized that the internal world and the natural world were forever separate and one never could be shown to be a form of the other (Kincheloe 1991). We understand now (but could not have understood then) that, despite the benefits of modernist scientific methods, this separation of mind and matter had profound and unfortunate consequences. Our ability to confront problems like the plague undoubtedly improved, as our power to control the "outside" world advanced. At the same time, however, we accomplished little in the attempt to comprehend our own consciousness or "inner experience" (Leshan and Margenau 1982). If we could not experience it directly through our senses, then we could not deal with it.

Critical Pedagogical Research: Postmodernist Redux

Much confusion exists over the meaning of the concept of postmodernism or postmodernity and the difference between postmodernism and postmodernity. Postmodernism refers to a way of seeing the world, a philosophical position. Postmodernism is also labeled the postmodern critique. As "popularity" in the use of the term postmodern has fallen under attack, for the purpose of clarity and not engaging in a discourse war, we refer to our work (which could be considered postmodern) as critical. Postmodernity is a periodizing concept (i.e., the era that follows modernity). Debates rage around *when* postmodernity supplanted modernity or *if* postmodernity supplanted modernity. Another contentious question involves the degree to which postmodernity constitutes a complete break with modernity. Is postmodernity a separate era? Or is it merely an extension of modernity? Using the descriptor of critical, we remove the historicizing and positionalizing nature of postmodern and move to the political and ideological nature. The process of analyzing the relationship between postmodernity/postmodernism – which we will now refer to as critical research – and research in science education clarifies these conversations.

Critical social research (in the critical pedagogical/theoretical sense) can be labeled as "hyperreal" – this implies researching an information society which is socially saturated with ever-increasing forms of representation (e.g., filmic, photographic, and electronic) all of which have had a profound effect on constructing the cultural narratives that shape our identities. The drama of living has been portrayed so often on television that individuals are increasingly able to predict the outcomes to be the "natural" and "normal" course of social life (Gergen 1991). As many critical cultural studies analysts have put it, we become pastiches or imitative conglomerations of one another. In such a condition, we approach life with low affect (a cool pose) and a sense of critical and postmodern ennui. Our emotional bonds are diffused as television, computers, DVRs, and iPods assault us with representations that have shaped our cognitive and affective facilities in ways that still remain insufficiently understood. The need for immediate communication gratification has plunged the linked-in, connected, wired masses in such a way that science is usurped by nontheoretical, nonprofessional commentary, and viral science becomes the dominant discourse. An example of a postmodern science event was clear in the 2009 swine flu culture of fear created by tweets, Facebook, and MySpace pages, and mainstream news stations creating feeds based on those viral announcements of the spread of epidemic. News became saturated with news about news, news from social network sites, and as afterthoughts, doctors and researchers were brought in to discuss the possible epidemic. And, back to production of capital and profit, the "experts" employed also presented agenda-ridden commentaries, depending on their political, ideological stances, or on which pharmaceutical company's press releases and research were being used.

It is misleading merely to identify postmodernism (the philosophical critique) and critical research bricolage with poststructuralism. Poststructuralism has attacked the premises and assumptions of structuralism and its attempt to create a scientific basis for the study of culture. Grounded on a firm belief in certainty and objectivity, structuralists posited that an unchanging and fixed human nature existed and could be described accurately by scientific methods. For example, intelligence was fixed and could be precisely measured by IQ tests. Poststructuralists have denied the existence of scientific certainty, arguing that human identity and consciousness are historically produced. Therefore, identity and consciousness take on different forms in different eras (Best and Kellner 1991). In this context, there are many similarities between postmodernism, postructuralism, and critical bricolage but they differ as to their referents. Postmodernism (the critique) is an umbrella category pertaining to a range of philosophical positions that critique the modernist thought produced in Western societies during and after the Enlightenment. Poststructuralism is an academic discourse that subverts particular scientific practices that assumed an unproblematic representation of the nature of reality. Poststructuralism is a critical postmodernist discourse, but not all critical or postmodern expressions are postructuralist. Critical bricolage can simplistically appear as a mixed-research methodology. While, indeed, different "methodologies" are employed, bricolage cloaks itself within a critical theoretical commitment to social justice and a critical pedagogical underpinning combining theory, discourse, identity, and the political.

The critical research bricolage we are proposing is not only based on critique. The synergism of the conversation between the research bricolage and critical theory involves an interplay between the praxis of the critical and the radical uncertainty of what is often referred to as the postmodern. As it invokes its emancipatory strategies for the emancipation of meaning, critical theoretical bricolage provides the postmodern critique with a normative foundation (i.e., a basis for distinguishing between oppressive and liberatory social relations). Without such a foundation, the postmodern critique is vulnerable to nihilism and inaction. Indeed, normatively ungrounded postmodern critique is incapable of providing an ethically challenging and politically transformative program of action. We argue that, if the critical pedagogical (postmodern) critique is to make a valuable contribution to the notion of schooling as an emancipatory form of cultural politics, it must make connections to those egalitarian impulses of modernism that contribute to an emancipatory democracy. In doing this, the project of an emancipatory democracy and the schooling that supports it can be extended by new understandings of how power operates and by incorporating groups who had been excluded by their race, gender, sexuality, ableness, religion, or class (Kincheloe and Steinberg 2008).

Critical research has never been reluctant to point out the limitations of empirical research, calling attention to the inability of traditional models of inquiry to escape the boundaries of a narrative realism. However, the research bricolage does not exclude empirical work; indeed, certain data can only serve to further the thickening of the tentative interpretation by the researcher. The rigorous methodological approaches of empirical inquiry often preclude larger interpretations of the forces that shape both the researcher and the researched. Empirical observation cannot supplant theoretical analysis and critical reflection. The project of critical research is not simply the empirical representation of the world but the transgressive task of posing research itself as a set of ideological practices. Empirical analysis needs to be interrogated in order to uncover the contradictions and negations embodied in any objective description. Critical researchers maintain that the meaning of an experience or an observation is not self-evident. The meaning of any experience depends on the struggle over the interpretation and definition of that experience (Weiler 1988).

The ways in which we analyze and interpret empirical data are conditioned by the theoretical frames used and dependent on the researcher's own ideological assumptions. The empirical data derived from any study cannot be treated as simple irrefutable facts. The employment of instrumentally rational positivist readings of data does not serve to present any type of truth except the "truth" which is predetermined by the researcher (due to the choice of methodology and positivist reading). They represent hidden assumptions, which the critical researcher must dig out and expose. As Einstein and Heisenberg pointed out long ago, what we see is not what we see but what we perceive (Kincheloe et al. 1999). The knowledge that the world yields has to be interpreted by men and women who are a part of that world. What we call information always involves an act of human judgment. From a critical perspective, this act of judgment or interpretation is a theoretical act (Kincheloe 1991). Critical analysts contend that theory involves understanding the relationship between the particular and the whole and between the subject and the object of analysis. Such a position contradicts the traditional empiricist contention that theory is basically a matter of classifying objective data.

Critical Cultural Studies Research

Over the last two decades, cultural studies' popularity has increased in universities throughout the world. As an interdisciplinary, transdisciplinary, and sometimes counter-disciplinary field, cultural studies functions within the dynamics of competing definitions of culture. Rather than equating culture with high culture, cultural studies assert that myriad expressions of cultural production should be analyzed in relation to other cultural dynamics and social and historical structures. Attempting to connect critical theory with the particularity of everyday experience, students of cultural studies argue that all experience is vulnerable to ideological inscription. At the same time, researchers maintained that theorizing outside of everyday experience results in formal and deterministic theory.

While cultural studies are associated with the study of popular culture, it is not primarily *about* popular culture. Cultural studies is broader and involves the production and nature of the rules of inclusivity and exclusivity that guide academic evaluation, particularly the way in which these rules shape and are shaped by relations of power. Such insights are especially important for research in science education, as they allow insights into scientific assumptions typically outside the purview of the field (Steinberg 2006).

Like any critical field of research, cultural studies are concerned with their application to the world outside the academy. Proponents maintain that cultural studies should address the most urgent social questions of the day in the most rigorous intellectual manner available. Thus, the everyday concerns of cultural studies are contextually bound. So important is this notion of context that some scholars label the work of cultural studies as "radical contextualism." Science researchers should also understand that the popular and the contextual often lead to better scientific research and certainly better scientific pedagogy (Emdin 2009).

Critical Research: Employing The Bricolage

This section starts by discussing the need for the critical researcher to be eclectic in choosing from a wide range of critical postmodern research methods. Then, detailed consideration is given to two critical scientific methods: semiotics and critical ethnography.

The Eclectic Methods of the Critical Researcher

The attempt to construct a universal critical pedagogical research method is as futile as physicists' quest for the ether. Because critical research in science education can make no guarantee about what particular questions will be important in varying contexts, one methodology cannot be privileged over others; at the same time, none can be eliminated without due examination. Ethnography, textual analysis, semiotics, deconstruction, critical hermeneutics, interviews, phonemic analysis, psychoanalysis, rhizomatics, content analysis, survey research, and phenomenology only begin a list of methods which a critical researcher might bring to the table (e.g., Kincheloe and Berry 2004). Such an eclectic view of research has been labeled *bricolage* (Denzin and Lincoln 1994), which involves taking research strategies from a variety of disciplines and traditions as they are needed in the unfolding context of the research situation. Such a position is pragmatic and strategic and demands self-consciousness and an awareness of context from the researcher. Borrowing from the term coined by Claude Levi-Strauss, Denzin and Lincoln allude to the possibilities engaged by creating a multilayered complex research methodology.

The critical eclectic researcher is able to negotiate a panoply of data-gathering techniques and a plethora of interpretive theoretical constructs (e.g., feminism, Marxism, cultural studies, critical constructivism, critical theory, critical/resistance postmodernism). Most critical methods can be deployed at some point in one context or another to achieve critical postmodern goals. Such efforts hinge on the researchers' theoretical understanding of the critical tradition and their ability to apply this understanding to the social and interpersonal aspects of his or her life (e.g., understanding the relationship between one's "way of seeing" and the race, class, and gender location of personal history). In appreciating research as a political act, the critical bricoleur abandons the quest for objectivity and instead focuses on the clarification of the values that he or she brings to the inquiry (Denzin and Lincoln 1994). We follow with two examples of qualitative "methodology" which can be combined within a bricolaged approach.

Semiotics

A couple of examples of critical methods in education are in order. Semiotics is the study of codes and signs that help humans derive meaning from their surroundings. Science education researchers can use semiotic methods to gain insights into deep structures moving classroom events. Indeed, classrooms are diamond mines for semiotic study for they abound in codes, signs, and conventions that call for unique insight. Examples of the many school topics which a semiotician could study are the way in which teachers, students and administrators dress, pupils' language when speaking to teachers as compared to conversations with classmates, graffiti in a middle school restroom, systems of rules of behavior, the use of bells in schools, memos sent to parents, language used by students to describe science and scientists, and the nature of the local community's conversation about school athletics. Critical researchers of the profound in the mundane begin to move beyond traditional questions of teaching to inquiries about who we are becoming as a result of this science education experience (Britzman 1991).

Semiotics makes the given an object of thought and critical focus. Semiotics refuses the shallowness of lived experience, as it searches for ways of seeing that describe the invisible. Viewed from this perspective of the critical, a gifted program in science involves far more than a set of enrichment activities for the smarter children. Levels of obscured assumptions begin to jump out of such programs when the light of grounded critique is shone upon them. Thus, research moves from the glorification of the novel to the analysis of the assumed. In this context, language transcends its role as conduit for information. Semiotic analysts view the relationship between speaker and listener or writer and reader to be based on constant interpretation in the context of the semiotic matrices brought to the act of communication by all participants. Thus, communication becomes not a matter of extracting meaning from communiqués, but of constituting meaning based on the cultural context, values, and social identities of those involved (Manning and Cullum-Swan 1994).

When researchers turn such interpretive strategies upon their own practice, they engage in semiotics of introspection. As researchers analyze their actions with attention to ritual, metaphor, and questioning strategies, they uncover hidden dimensions of their belief structures, their familiar cognitive strategies, their assumptions about students, and their attitudes toward the "proper" deportment of a teacher (Courteney 1988). No longer can knowledge producers hide in the shelter of the Cartesian–Newtonian objectivism, which shields them from the personal issues associated with all educational acts. Semiotic researchers cannot view themselves as transhistorical beings – they need to understand their place in the web from which they see reality. Contextualized in this way, the schemata, the values, and the belief structures that defy recognition as they fade in the familiarity of our consciousness are highlighted as the ink of semiotics dyes them. Historical contextualization of self in this situation utilizes the insight of difference, as we finally begin to see ourselves when we are placed against a social backdrop of values and ways of perceiving that are unfamiliar (Kellner 1991).

Critical Ethnography

Critical ethnography is another example of a critical research methodology that can be adapted to the bricolage. Ethnography (the study of events as they evolve in their natural setting) often is described as the most basic form of social research. While ethnographers disagree over the relative importance of each purpose, ethnography attempts to gain knowledge about a particular culture, to identify patterns of social interaction, and to develop holistic interpretations of societies and social institutions. Thus, ethnography in education attempts to understand the nature of schools and other educational agencies in these ways, and seeks to appreciate the social processes, which move educational events. Ethnography attempts to make explicit the assumptions, which one takes for granted as a culture member. The culture could be as broad as Japanese culture or as narrow as upper-middle-class student culture of George Washington High School. The critical ethnographer of education seeks to describe the concrete experiences of everyday school or educational life and the social patterns, which construct it. One of the most basic tools of the critical researcher is derived from the ethnographic tradition (Clough 1992).

Critical forms of ethnography have focused on the discontinuities, contradictions, and inconsistencies of cultural expression and human action. As opposed to modernist forms of ethnography, postmodern methods refuse the attempt to reconcile the differences once and for all. The postmodern critique of classical ethnography highlights the tendency of the tradition to privilege a dominant narrative and a unitary, privileged vantage point. In the effort to conflate knower and known, the postmodern ethnographer proposes a dialogue between the researcher and the researched that attempts to smash traditional hierarchical relations between them (Atkinson and Hammersley 1994). In the process, the modernist notion of ethnography as an instrument of enlightenment and civilization of the "native" *objects* of study dies an overdue death.

Critical ethnographies are texts to be argued over whose meanings are never "natural" but are constructed by circumstance. Such characteristics obviously are colored by postmodern ethnography's rendezvous with contemporary literacy criticism and its Derridian influences (Aronowitz 1993).

Some of the critical ethnographies of the last few years have taken a ludic turn, ignoring critical concerns while pursuing a high-vogue deconstructionist posture. Such practitioners avoid any epistemology that promotes critical action for socio-economic change (West 1991). Critical ethnographers have slammed such ludic practice, joining with feminist, African-American, and postcolonial researchers to reemphasize questions of power's impact on identity, history, and social relations. The critical ethnography associated with feminism, anti-racism and postcolonialism has exposed the status quo apologetics of both traditional and ludic postmodern ethnography. Advocates argue that, in the tradition established by critical ethnography, practitioners must continue to document the rituals of resistance that have separated class cultures and subcultures from dominant society (Aronowitz 1993).

Facilitating the Work of the Bricoleur

By using the examples of semiotics and ethnography as two research concepts that can be employed with a bricolaged methodology, we introduce the unlimited notion of rigor vis-à-vis blending various qualitative methods to create a deep reading and interpretation of research. The bricolage is a critical approach, which understands that the frontiers of knowledge work best in the liminal zones where disciplines collide. Thus, in the deep interdisciplinarity of the bricolage, researchers learn to engage in a form of boundary work. Such scholarly labor involves establishing diverse networks and conferences where synergistic interactions can take place as proponents of different methodologies, students of divergent subject matters, and individuals confronted with different problems interact. In this context, scholars learn across these domains and educate intermediaries who can build bridges between various territories. As disciplinary intermediaries operating as bricoleurs facilitate this boundary work, they create conceptual and electronic links that help researchers in different domains interact. If the cutting edge of research lives at the intersection of disciplinary borders, then developing the bricolage is a key strategy in the development of rigorous and innovative research. The facilitation and cultivation of boundary work is a central element of this process.

There is nothing simple about conducting research at the interdisciplinary frontier. Many scholars report that the effort to develop expertise in different disciplines and research methodologies demands more than a casual acquaintance with the literature of a domain. In this context there is a need for personal interaction between representatives from diverse disciplinary domains and scholarly projects to facilitate these encounters. Many researchers find it extremely difficult to make sense of "outside" fields and the more disciplines a researcher scans the harder the process becomes. If the scholar does not have access to historical dimensions of the field, the contexts that envelope the research methods used and the knowledge produced in the area, or contemporary currents involving debates and controversies in the discipline, the boundary work of the bricolage becomes exceedingly frustrating and futile. Proponents of the bricolage must help develop specific strategies for facilitating this complicated form of scholarly labor.

In this context we come to understand that a key aspect of "doing bricolage" involves the development of conceptual tools for boundary work. Such tools might include the promotion and cultivation of detailed reviews of research in a particular domain written with the needs of bricoleurs in mind. Researchers from a variety of disciplinary domains should develop information for bricolage projects. Hypertextual projects that provide conceptual matrices for bringing together diverse literatures, examples of data produced by different research methods, connective insights, and bibliographic compilations can be undertaken by bricoleurs with the help of information professionals. Such projects would integrate a variety of conceptual understandings including the previously mentioned historical, contextual, and contemporary currents of disciplines.

Doug Kellner (1991) is helpful in this context with his argument that multiperspectival approaches to research may not be very helpful unless the object of inquiry and the various methods used to study it are situated historically. In this way the forces operating to socially construct all elements of the research process are understood, an appreciation that leads to a grasp of new relationships and connections. Such an appreciation opens new interpretive windows that lead to more rigorous modes of analysis and interpretation. This historicization of the research and the researched is an intrinsic aspect of the bricolage and the education of the bricoleur. Since learning to become a bricoleur is a lifelong process, what we are discussing here relates to the lifelong curriculum for preparing bricoleurs.

Also necessary to this boundary work and the education of the bricoleur are social-theoretical and hermeneutical understandings. Social theory alerts bricoleurs to the implicit assumptions within particular approaches to research and the ways they shape their findings. With grounding in social theory, bricoleurs can make more informed decisions about the nature of the knowledge produced in the field and how researchers discern the worth of the knowledge they themselves produce. With the benefit of hermeneutics, bricoleurs are empowered to synthesize data collected via multiple methods. In the hermeneutic process, this ability to synthesize diverse information moves the bricoleur to a more sophisticated level of meaning making. Life on the disciplinary boundaries is never easy, but the rewards to be derived from the hardwork demanded are profound.

Implications for Science Education Researchers

Science educators can learn from their encounter with the vicissitudes of scientific research. Critical research bricolage, and the educational forms emerging from it assume that science educators must understand the conditions and effects of knowledge production, while engaging in knowledge production themselves. In the present regime, this strikes us as a difficult or insurmountable task, given our experiences with science educators and science education students and the brilliance which they bring to their tasks. We believe that such understandings are possible. As knowledge producers, science educators can weave understandings of knowledge validation, student experience, and the notion of consciousness construction with the latest research in, say, quantum physics or molecular biology. Students can be introduced to the ethnographic, semiotic, phenomenological, critical hermeneutical, deconstructive, and psychoanalytical dimensions of the bricolage in the process of coming to understand the social, political, and epistemological forces that shape science, education, and their lives in general. In this context, science educators gain the ability to step back from the world and look at it anew. In seeing from a perspective different from the one to which they have been conditioned, science educators uncover new vantage points to observe the constructing forces (Adler 1991). As they produce knowledge, they remake their professional lives and they rename their worlds.

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Chapter 96
Analyzing Verbal Data: An Object Lesson

Wolff-Michael Roth and Pei-Ling Hsu

One of the most difficult aspects of doing qualitative research is to learn how to analyze verbal data in ways that can stand up to the experimentalists' perennial charge of engaging in subjectivist interpretations and "anything goes." Confronted with the task of analyzing verbal data, many graduate students in science education find themselves struggling to produce a persuasive and founded analysis. This chapter constitutes an "object lesson," a term used to denote a "striking example of a principle or ideal" (OED 2008), in the qualitative analysis of verbal data. We ground ourselves in the human, everyday competencies of speaking and understanding a language to develop a theoretical framework for understanding expertise in the analysis of verbal data. We develop this framework in the course of providing a reading of an experienced expert in the process of analyzing a previously unknown conversation transcript as part of a graduate course. This analysis, therefore, reveals how an experienced analyst makes sense of the conversation situation solely from verbal data on which the analysis is based when he does not have recourse to outside explanatory concepts (such as power, background knowledge, intelligence, institutional relations, etc.). Because the "owner" of the data sources was available, the expert's readings of the transcript could be checked against the situation from which the tape was culled. This comparison allows us to demonstrate the "veracity" of the "invisible cues" drawn on by the analyst to restore and reproduce the conversation situation. Through analyzing the expert's analysis in the teaching discourse, we make explicit recommendations for three important dimensions of qualitative research: the practice of analyzing verbal data sources and the teaching and learning of data analysis. We draw on the following excerpt from a lesson, in which a professor analyzes verbal data for the benefits of the students in a graduate course on qualitative research.

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Analyzing Verbal Data

Two students have brought to the master's-level class in qualitative research methods a transcript that they have prepared from a video (Table 96.1) unknown to their professor. They have presented the data in table form, one column per speaker; the data are projected at a screen so that all students have access to the transcript. The professor, a researcher with more than 20 years of experience analyzing verbal data, asks the two not to reveal the context or background of the data source. The point of this section of the lesson is to provide a reading of a transcript that reveals as much as possible about the original event. The following transcript takes us from a point 7′15″ to 11′30″ in the tape:

> And then here with Heidi talking about hallucination eh, "When you get out there you want to take." See, what I am trying is to. I don't have a starting point. I mean, I am, I am cold. I am starting cold. And in order to get into I try to elaborate and try to first describe what I see going on but also explain and link it to other things. So "when we get around here you want to take a look around and see if there is any landform that look like something that would be fa-familiar to you." And we we already hear that as it as a picking up a theme that eh already appeared in the first statement and later on about um, um "looking differently". It's all about perception and how things look and how they might look like other things um that they were familiar with. "Landforms that look like something that would be familiar to you." Not just like rock, but like something else. Um. "So what do you think that landform over there is like?" You probably all played this eh as kids looking at the sky oh a sheep oh eh something else. Um. That's what I kind of wha- what this generates the ideas. And if I'm blank with the analysis, these are the kind of things that I build from. So, what, that I built describe to get myself started. "So what do you think that the landform over there is? Does this one look like anything to you?" If I stop now, again, and I think about what kind of relations are there. Um. Well the three, they haven't talked yet at all, ehm they, w- whatever I said, the the the image I have. I haven't seen the video. The image I have maybe uhn people unfamiliar with the wilderness and maybe eh younger eh eh people. There is David and there is someone that functions in a situation where the kinds of questions seem to p- uh presuppose that the person already knows the answer. "So what do you think? What do you think that the eh that landform over there is? Does this one look like anything to you?" It's a question that seems to already – There is something in this question that make me, makes me think that the person already knows the answer. Or knows an answer. But it's not asked like. It's not like in a situation where um, where a person says: "oh that look like a sheep eh eh to me" or, um, you know a question, "What time is it? And well and you respond. Whereas in teacherly discourse you have, "What time is it?" And it's asked in a way wh- where the person already has the right answer. And and these seem to be the the kinds eh of a question th- an- and the the person, the relation of the person to the others. So a- you see how m eh even without having seen the video how eh, I'm eh attempting to provide a description of the situation what's happening here. "Hum, oh, that rock there looks like a camel. Oh no, that's it." I haven't been there, but the person saying: "that's it" confirms that the answer was the one that's prefigured, preconceived in in the question. "So what do you think that landform over there is?" Um there is a children's game. "Do you know what I think?" Or you look at the some cloud, "I see.... What do I see?"

The professor then continues for another 20 min. In the 30-min session, he will have covered 22 turns with a total of 283 words of transcribed text. He ends his talk saying that in working with and at the text, the researcher is much like a modern-day Sherlock Holmes, piecing together a story from and in the materials at hand. The students who had brought the verbal data state at the end that the professor got the

Table 96.1 The professor in our narrative analyzes in real time this student-generated transcript

David Suzuki	Heidi	Amanda	Michael	Ashley
	It's amazing how the landforms here really look like other things other than rocks. Do you notice that sometimes?			
		Yeah		
				Yeah
			Yeah	
	It's funny			
As long as you've got a good imagination				
	Well, we've noticed that maybe, yeah, maybe let's go down this way. We noticed that the longer you're out in the badlands, and the hotter it is, the more things look like things			
Yeah-ha-ha-ha. You're imagination gets looser, huh?				
	Well, it does. Some people claim it might be a kind of hallucination – now watch out for the cactus. When we get around here, you want to take a look around and see if there's any landforms that look like something that would be familiar to you, not just like a rock.			
	So what do you think that landform over there is? Does this one look, look like anything to you?			
		Hmm. Oh! That rock right there looks like a camel		
	Oh…no…..that's it! We actually have a name for this guy. We call him Fred the camel….see the hump….see the big droopy lips pointing to the left. And if you look off in the back can you see anything else?			

entire story right, including the institutional relations between participants, type of place, and type of event. The conversations after this object lesson testify to the fact that the students have understood their professor despite the mumbles, stumbles, repetitions, stops, restarts, ungrammatical phrasings, and so on.

Analyzing an Analyst Analyzing

Qualitative data analysis often is taken in our discipline as a matter of "interpretation," inferring what is *behind* and bringing *out* meaning of, for example, the intents and intentions of people, the knowledge in their heads, their motives and beliefs, and so forth. The problem then is one of making the interpretation reliable ("viable"), which means, arriving at descriptions and explanations that ascertain a relation between the outcome of analysis and the nature of the phenomenon. Some qualitative researchers, therefore, resort to techniques such as *triangulation*. This technique presupposes that there is a phenomenon that reveals itself in different documents, collected at different times, and all referring to the same underlying psychological phenomenon so that it can be located and detected by means of direction measurements from multiple positions (contexts). The techniques also include *grounded theory* (Corbin and Strauss 1990), a method that attempts to build a *coherent* framework valid within the data set collected by or available to the analyst. The difficulties are tremendous, especially for self-avowed constructivists who seek to establish coherence in a world inaccessible to them, and about which they construct structured and repeatable patterns in their minds. Because the constructivist cannot establish truths, patterns are accepted when they prove "viable."

What does the professor analyst in our transcript do? Evidently, he *works with* materially inscribed text. And he does so by *working right at* the text. He already has told his audience that importing concepts such as power is not permissible in the form of analysis that he demonstrates and advocates. Similarly, what do we do? How is it that we can identify different orientations within the professor's talk even without having the original videotape available showing him when he conducts a public first- and real-time analysis of the provided transcript? In this episode, the professor reads from the transcript, an utterance Heidi has made, and then explains to his audience to note what he is in the process of doing ("What I am trying… to"). He suggests not having a starting point for his analysis, which makes immediate sense given that he received the transcript only instances before and looks at it for a first time. He explicates that he begins this, as any analysis by describing what he sees and that he explains it by linking the present topic to others. He then returns to reading the next sentence and refers to picking up a theme, something that already appeared in the first statement in the transcript, something "about looking differently." He moves to elaborate that it is all about perception – previously he has already talked about David Suzuki's comment about imagination and Heidi's mention of hallucination – and about "how things look and how they might look like other things that they were familiar with." He continues by expounding on the theme that is *at work in* the text, looking at something and asking what it looks like, some other things already familiar to the onlooker. The professor orients to his audience and suggests that they probably know this game. He then provides another explanation, that whatever he has just done is the way in which he approaches this form of data analysis and that "this is what [he] build[s] from." He reads two sentences from the transcript, and then interrupts his reading again to begin talking about the process of analysis.

He notes that "the three" (whom we might hypothesize to be Amanda, Michael, and Ashley) have not yet talked (which confirms the hypothesis, as these three have not yet talked – much) and then talks about the image although he has not seen the video [from which the transcript was produced]. He talks about what the text so far evokes for him, namely, "younger people." One of the persons is called David Suzuki, which is the name of a well-known Canadian, former geneticist and science broadcaster, and environmentalist activist – but are the two, the well-known Canadian and the person in the transcript the same? The professor then talks about what he hears, namely, "kinds of questions [that] seem to presuppose that the person already knows the answer." Here the professor appears to draw on an understanding of the world that allows him to distinguish between preformatted questions, questions that have as their purpose to solicit responses that are then evaluated by the questioning individual. He then glosses the questions again, "So what do you think?" "What do you think the landform over there is?" "Does this one look like anything to you?" He continues with what we hear to be an explanation. He suggests that these are questions that "make him think that the person already knows the answer or knows an answer." The professor proceeds to elaborate, now specifying how the situation differs from others where a person would say, "Oh that looks like a sheep to me" or where a person asks a question like "Do you know what time it is?"

Without apparent transition, at least at the level of the text, the professor continues reading the transcript ("Hum, oh, that rock there looks like a camel. Oh no that's it."). Testing the identified transitions against the videotape of the professor at work, we note that these shifts correspond to shifts in his orientation from the text on the computer screen toward his students and back to the text on the screen. He then says that he has not been there but that the utterance "that's it" (Heidi) confirms (to him) that the answer was the prefigured, preconceived one. He rereads the question and then tells his audience that there is a game. He elaborates by restating, "Do you know what I think?" or, looking at a cloud, "What do I see?"

Readers should note that, in this analysis so far, we have not said or speculated about what the professor has in his mind or his intentions other than what he declares to be his intentions. We can see him operating with what feels like a sense of a game both for his analysis and for the situation that is unfolding. As he *works through* and *right at* the text, overhearing the people in the transcript interact with one another, he develops an image of the situation. It is not that *we* attribute an image to him; rather, this is what he tells his audience in the seminar room and makes available for the class and analysts like us, because the event was video recorded. In addition, he tells us to be developing something like a hypothesis ("the kinds of questions seem to p- uh presuppose that the person already knows the answer") – here he hears, as he tells the audience, preformatted questions. He thereby allows the audience (students and us) *during* his analysis to witness the point where (when and how) he forms a hypothesis that is actually confirmed when Heidi responds in a particular way to Amanda's response to a preceding question in a later part of the transcript.

What is it that allows us to overhear (read) an utterance as a question? One sign is the punctuation, which already illustrates the competencies of the transcriber at work, who hears an utterance as a question. This is so even if the transcriber does not know anything about conversation analysis, which takes turn pairs as the minimal unit of analysis. In this case, the analyst takes the conversation as the event to be explained and the participants as its constituent but irreducible moments. This provides for a coherence across speakers, who speak not as monads but who speak already oriented toward the other; this other provides a social evaluation of the utterance, an evaluation that the original speaker monitors (Bakhtin 1981). That is, at the level of the conversation, the analyst cannot presuppose that an utterance is a question – he has no access to intentions unless the participants articulate them – or unless there is a question–response pair. The response lets the initial speaker and the audience know what the effect of the preceding utterance is and has been.

The response itself becomes the first and irreducible part of the next turn pair (unit). This approach to verbal interactions guarantees that the conversation comes to constitute an irreducible whole that develops because of internal forces and which is inherently connected rather than a seriation of monadic articulations in specific, contingent settings. The internal connection exists because each utterance is both the completion of one and the beginning of the next speech act, like a sprocket pushing and pulling along another wheel by inserting itself between a pair of its sprockets. In the present instance, the professor does not just take an utterance as a question, even though the question mark, which the student transcribers placed at the end of Heidi's utterances, suggests that *they* had heard a question even without knowing about I-R-E sequences and the assumptions conversation analysts make about the nature of conversational turns. Rather, we see the professor producing a hypothesis about what possibly is happening here, before confirming the utterance as the first part of a question–response pair, or, rather, as the first part of the triadic I-R-E sequence.

We can see the professor work *with*, *through*, and *right at* the text. He does not impute thoughts, as he says, and throughout his lessons, he makes salient each and every time a student attributes ideas, thoughts, motives, emotions, intents, beliefs, or attitudes to the actors that appear in the transcripts or on the videotapes. He works, as he says elsewhere in the seminar, only with direct evidence. Which is precisely what *we* do when analyzing his talk – we only work with direct evidence and do not make attributions about ideas, thoughts, intentions, and so on. He repeatedly warns students not to impose high-level, abstract concepts such as power but rather to engage in the work of showing how, if relevant, power differential is the outcome of interaction specifics. In the present episode, we see him, for example, point to the fact that the particulars of the question–response pairs in the transcript at hand are typical for situations in which the person asking already knows the answer and thereby positions and repositions the person with respect to others as the one *in the know*

(Roth and Middleton 2006). “It is a form of relation,” he suggests here and adds, sometime later, that it is a turn-taking sequence typical for school settings. Elsewhere in the transcript he elaborates that researchers have identified the pattern of teacher *i*nitiation, student *r*esponse, and teacher *e*valuation, which has given rise to the well-known acronym I-R-E (e.g., Lemke 1990). Accordingly, there are two turn pairs at work, the first constituting a question that initiates the sequence, which is completed by the constitutive response. (This is not a causal pattern, and if a student were to show a middle finger, then a very different turn-taking pattern would unfold.) The response is the utterance that initiates another turn pair, which is completed in and by means of the evaluation. In case of trouble, there may be extended inquiries at work prior to the pronouncement of the evaluation. Here, the question already is oriented to not just the student response but to the subsequent teacher utterance. That is, this talk is not monadic, produced by subjects caught in their utter singularity, but is societal through and through, produced by historical subjects caught up in and surrounded and formed by a cultural-historical world inherently shot through with meaning. Participants draw on a language that is not theirs but which they concretize and mobilize for intentions to which we, analysts, often are not privy. And they do so not entirely freely but always realizing and mobilizing constraints and affordances inherent in the language and culture at a particular point in microgenetic, ontogenetic, and cultural-historical time. It is as if language made use of human subjects to realize itself in the face of and despite the personal intentions and subjectivities the latter ascribe to themselves.

The Analyst, His Participants, and Their (Common) Ethno-Methods

There are at least two types of events available in the materials presented here. At a first level, David Suzuki and four other individuals not only talk about an aspect of the environment (the topic of conversations) but also constitute the situation for the one it demonstrably is (the ethno-methods of conversations). That is, in articulating certain features of the conversation and its topic as a recognizable form of interaction, which led him to the hypothesis that it is some outdoor program perhaps in a national park, the professor points us to the fact that human beings first and foremost have to establish the situation itself within which their talk comes to make sense. They draw on and realize particular, repeated, and recognizable interactional forms, such as the I-R-E sequence, to produce the situation as one that it recognizably is. In a similar way, we, the authors of the chapter and others working, as we do, *with, through*, and *right at* texts, recognize the didactic features of the professor’s talk oriented to provide a description of the analyses he conducts, evidently moving seamlessly between the two forms of task orientations. Here, too, the talk about the contents and processes of what he does have a distinctive pedagogical ring. What allows us to state this? Again, it is our sense of the game, our knowledgeability about how the world is patterned and what kinds of situations we find therein.

In the limit, then, there is no difference between the professor's knowing the English language as exhibited in the analysis of knowing a language – the kind of topics it allows and the forms in which people produce and reproduce the topics – and knowing his way around the world. This is precisely the conclusion that the language philosopher Donald Davidson (1986) arrived at in his analysis of the minimal conditions for two persons to have conversations.

In this chapter, we therefore work with and through at least three levels of texts. On the first level, there is a piece of transcript that constitutes the data source with which the professor in the vignette works. The text that he produces constitutes a second level, for he reads and talks *about* the first text. Finally, our narrative constitutes a third level. These levels are not independent, for at all three levels, the subjects use the English language to talk about things. These three levels have different objects: some feature in the environment, the transcript for the professor, and the two transcripts and the chapter topic at the third level. But the three levels are deeply related because understanding *this* text also requires understanding the other two texts, one appearing in Table 96.1, the other as a transcript in the text. The professor, too, has to have an understanding of the English language, the world, and the relationship between words and the world that is of the same kind that the speakers in the original transcript have. The professor cannot know what the five people are talking about, what they are referring to, how they interact *unless* he already is familiar with the kind of world and relation that they established. This was clearly shown to us in the collaboration with a social psychologist during the analysis of think-aloud protocols/interview data involving an undergraduate physics/anthropology student, who, as part of his co-op program, collected data from his physics professors. The social psychologist misread/misheard the speakers in repeated instances because he was unfamiliar in instances where the speakers mobilized Standard English with specific semantics in mathematical physics.

There is more to language. The professor in fact already operates at multiple levels with the language – or, shall we say, always operates with different orientations/forms of English – as he both analyzes the data in real time and talks about how he analyses the data. More so, in the analysis of the professor at work with the text, we make distinctions about when the professor is reading and when he speaks to the audience to provide an explanation. There is a multi-voicedness *in* and *of* the text, a heteroglossia (Bakhtin 1981), which challenges simple and literal readings attempting to make attributions to some hidden mind "behind" the text. This acuity for detecting heteroglossia, too, we have to bring as competence for detecting differences in the text, although, at a textual level, this often is a difficult to impossible task. But this also shows us that the two forms of language, that of the analyst and that of the teacher do not significantly differ. It is the same English, but it is also a different English. One takes the transcript as *object* of the analytic activity, and the other one takes the transcript as *tool* for the teaching purpose. The two are different activity systems, with very different inherent dynamics and object/motives, and, according to cultural-historical activity theorists, with very different forms of consciousness and therefore with very different forms of idea systems, ideologies (Bakhtine [Volochinov] 1977).

The five speakers in the transcript (Table 96.1) make available to each other precisely those resources that they require for conducting the activity in progress. Those aspects of the setting that go without saying do not have to be articulated, for they would be stating the self-evident. To understand what the speakers are talking about, the analyst, therefore, requires the *same* sorts of competencies and methods, in all their variations that normal conversation participants in these sorts of setting bring to the situation and that are sufficient to do what they are doing. These competencies and methods are those of the people, *ethnos*, so that we are actually in the process of identifying *ethno-methods*. The purposes of the analysis are not to *infer* what goes on in the minds of the participants but to articulate and explain what they are doing and how they are doing it by drawing only on those resources that the participants also have at their disposal. In this form of analysis, analysts do not attempt to get into the heads of people. They restrain from attributing any attribute to others for which there is not clear evidence provided, that is, what people do not already make available for others in the situation. Thus, we do not know what Heidi's intentions are, or those of David Suzuki. At the beginning of the session, the professor articulates for the students that the name "David Suzuki" provides resources for reading the transcript; but these resources may in fact lead the analyst astray, especially if they lead him to making attributions that the transcript ultimately does not bear out. Thus, the professor does not presuppose that "David Suzuki" is an expert *beforehand* and then only focuses on how *the expert teaches* others. However, the professor analyzes *the process* of this conversation, the way *participants cooperate* to achieve topical cohesion, teaching–learning, and other forms of engagement with the world. As analysts, we do not attribute to others what they see unless they clearly articulate for others what it is that they perceive and what they are attuned to. In the same way, we do not attribute to the professor thoughts, motives, emotions, beliefs, attitudes, and so on unless he specifically articulates them for the audience and therefore as a resource for doing and accomplishing the work/task at hand. Thus, he tells his audience, and therefore the analyst as well, what he sees, hears, picks up on, is trying (attempting) to do, builds on, and thinks. These are the actions and intentions that the person is ascribing to himself, as a way of articulating what an expert does in the process of reading a transcript.

Teaching Methods for Analyzing Text

The Davidsonian position articulated above has both its advantages and its disadvantages. On the one hand, researchers can (and in fact have to) mobilize their everyday ethno-methods to figure out what their research participants (fellow people) say and do. Researchers do so by wit, luck, and wisdom gained in and through their life experiences and by other means not all of which are available to conscious reflection. On the other hand, because there is no other than this ethno-method at work, "there is no more chance of regularizing, or teaching, this process than there is of regularizing or teaching the process of creating new theories to cope with new data in any field – for this is what this process involves" (p. 246). To reproduce ethno-methods (culture), we therefore have to resort to the kind of teaching that is typical of practice in general – by observing and participating with experienced practitioners doing what the practice consists of, here analyzing written transcripts. This allows the newcomer analyst to observe analysis-in-action, which is "a protracted and eating task that is accomplished little by little, through a whole series of small rectifications and amendments inspired by what is called *le métier*, the 'know how', that is, by the set of principles that orients choices at once minute and decisive" (Bourdieu 1992, p. 228).

How does one teach to analyze in ways illustrated by the professor in our example? The episode itself already provides one possible answer: teaching this method of analysis may begin in a context not unlike the master's classes or workshops of other practical professions, including architecture, musical performance, or painters. Key in such sessions are less those aspects of practice that inherently lend themselves to description and explanation but those aspects that do not or cannot make it to the level of consciousness. An experienced professional, the teacher, performs under authentic conditions, in real time, and without time out. The students, and here the reader, can then observe the practitioner at work, exhibiting the very practices that constitute masterly performance. That is, in addition to the professor's *explicit teaching* about qualitative analysis, students (and authors) also have access to the professor's *implicit teaching* about the ethno-methods of analysis through the real time *praxis*. More so, in such situations, the structured and structuring dispositions – also denoted by the term *habitus* (Bourdieu 1992) – underlying the thematized practices, are made available not explicitly but as how they operate in and are constitutive of praxis. Scientific production, "presupposes a definite mode of perception, a set of principles of vision and di-vision" (p. 222). It cannot, therefore, be learned in the abstract, by reading a textbook, but has to be observed, done, and observed in doing. "There is no way to acquire it other than to make people see it in practical operation or to observe how this *scientific habitus*… 'reacts' in the face of practical choices… without necessarily explicating them in the form of formal precepts" (p. 222). This addresses the learning paradox that certain modes of thinking and actions, precisely those that are vital to a field, can be learned only "through total and practical modes of transmission founded upon direct and lasting contact between the one who teaches and the one who learns" (pp. 222–223).

In this chapter, however, our pedagogy operates at more than one level. We do not just show what an expert analyst of verbal data does, but we employ the same ethno-methods for exhibiting ethno-methods. On the one hand, we exhibit the minute-to-minute unfolding process of articulating a reading that an expert analyst provided for his students. Much like the students, readers can follow what the analyst focuses on, the temporal order of the ongoing process, and how he articulates his own analytic processes in the here and now of a master's class. On the other hand, drawing on the same methods, precepts, and practical understanding of how the world works, we describe and explicate the details of this analytic work at a second level. Rather than leading to an infinite regress, we suggest that the analytic objects, processes, and products are reflexive. At each level, the subjects involved draw on the same kind of understanding that the subjects on the other levels have to draw on for understanding.

David Suzuki hears and responds to Heidi, who hears David responding. The professor hears Heidi (as David does) and David (as Heidi does); and he articulates his hearing and his explications. We, the authors, hear Heidi and David, as these participants hear each other, and we hear the professor talk about what he hears being said and done in the interaction. That is, the subjects producing the original conversation work with the same materials and the same ethno-methods that are available to and used by the analysts at the subsequent two levels. These levels, therefore, are no different than the first, but rather fold methods and practical understanding back over itself.

Toward a Praxis of (Teaching) Methods

By means of a self-exemplifying and reflexive praxis of data analysis, we argue for methods of analyzing verbal data that do not impose on social actors, characteristics that they do not, would not, and could not ascribe to themselves and to each other. In so doing, we exemplify rigor, which here means that analysts not only take the verbal data as their objects but also stay right at the text. Our point is not that the professor "got it right," as confirmed by the data owners, but that working *with, on, through*, and *right at* the text, he provides a reading that exhibited the rationality, relations, dynamics, and so on of the situation. We operate with multiple levels of texts, and we do so for instructional (pedagogic) purposes. In the process, we make apparent the recursive, pervasive, and heterogeneous nature of language, which is the object, the tool, and the ground of the analysis. We describe and point to what the professor does, and in the process enact analysis with common ethno-methods. The fact that the professor is also one of the authors of this chapter is coincidental: any other analyst with similar theoretical and methodical inclination would have proceeded likewise. The difficulty for newcomers that arises from such an overlap lies in the temptation to use intentions otherwise hidden from view to generate (illegitimate) explanations that usually cannot be grounded by their data.

The position of the nature of talk and language developed in this chapter implies constraints on the teaching of methods for analyzing talk and language. Doing research is a praxis, *something that exists only when it is happening*, and as all praxis, involves a lot of unarticulated and unconscious know-how. It cannot, therefore, be taught, especially not by means of abstract descriptions, for these do not and inherently cannot mobilize that which remains hidden from consciousness. One has to experience them at work, with all the wavering, false starts, renunciations, impasses, problems, and so on that characterizes lived and living praxis.

In this chapter, we use expressions such as "working *with, on, through*, and *right at* the text." These choices are deliberate as they highlight several important aspects of analysis. One the one hand, the analyst takes the text (words) as his material that he works *with*. In so doing, he works *on* the text, literally the objectified object of his work. The focus of this analysis is what is done with words, their function, and the topics that the participants establish and maintain. The analyst does so by taking one turn pair at a time, slowly working *through* the text thereby slowing down the events. On the other hand, the work also is *right at* the text, without distance from it, the background the other form of work. The analyst does not move away from the text to seek theoretical discourses that are to be imposed but builds descriptions and explanations that show the work of discourse itself. He does so *with* the text, using the very discourse that the participants in the transcript make available to one another. Working *with*, *on*, *through*, and *right at* the text demands slowing down, patient reading and rereading, avoiding over-hastily attributing meaning and function that more careful readings do not subsequently substantiate.

Our approach offers a way of (practically) dealing with the perennial problem of the constructivist interpreter worried about getting caught in his own subjectivity. Constructivist interpreters face the problem that they cannot explain how conversations unfold so rapidly and apparently unproblematically. Their emphasis is laid on the individual agent and there is nothing in their framework that theorizes the fact that speakers do not just speak to themselves but speak *for* others, and *through* others for themselves. It requires each speaker to "interpret" the preceding speaker, construct a response, and then externalize this response. Speakers do so by drawing on language that has come to them *from* others to which language returns. The effects of *their* speech intentions are available only in and through the responses utterances solicit, so that the speech act is only complete with and available in the return. The speaker monitors this return to be able, if needed, to effect repair – for example, when the hearer articulates troubled understanding, intentions that differ from the speaker. That is, each speaker already orients not only toward the response on the part of the other but how to respond to the response even though this response is underdetermined. More so, each speaker *presupposes the intelligibility* of the utterance, which therefore is evidence for a grounded and accountable way of seeing, describing, and acting in the world.

We know from our own embodied and personal experience that the best way of learning how to do analysis is to do it together with an experienced practitioner. This is the way in which we practice it in our research laboratory, where people of very different background and experience gather to jointly analyze tapes and transcripts. This is not always possible, especially in research methods classes with and for larger groups of students. Doing public analysis of unknown data in real time, where there is no time out, is another option that practitioners may want to use to show how textual analysis and interpretation unfold and operate.

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