Part

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CONSTRUCTIVIST FRAMEWORKS

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The Role of Theoretical Frameworks in Chemistry/Science Education[1]

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Biography

George Bodner is the Arthur E. Kelly Distinguished Professor of Chemistry, Education, and Engineering at Purdue University. He began his academic career as a history/philosophy major at the institution now known as the University at Buffalo. He found, much to his amazement, that chemistry was fun, and changed his major under the mistaken impression that jobs were easier to find as a chemist. After a mediocre career as an undergraduate (B. S., 1969), he entered graduate school at Indiana University (Ph.D., 1972) where he apparently did well enough as a double major in inorganic and organic chemistry to gain an appointment as a visiting assistant professor at the University of Illinois (1972-1975). Two things became self-evident during his tenure at Illinois. He found that teaching was fun, and he realized that his research could best be described as searching for definitive answers to questions no one ever asked. When the time came to leave Illinois, he therefore took a job as two-thirds of the chemistry faculty at Stephens College where he lasted for two years (1975-1977), teaching general, organic, inorganic, and biochemistry. He moved to Purdue University in 1977 to take a position in something known as "chemical education." He is the author of more than 120 papers and 48 books or laboratory manuals. His interests include the development of materials to assist undergraduate instruction, research on how students learn, and the history and philosophy of science. Several years ago, he was selected to receive the Nyholm Medal from the Royal Society of Chemistry, the Pimentel Award in Chemical Education from the American Chemical Society, and the Distinguished Alumni Award from his alma mater, the University at Buffalo.

Introduction

This chapter tries to summarize some of what the author has learned while working with graduate students pursuing research-based M.S. and/or Ph.D. degrees in chemical education. It tries to describe the three fundamental elements of a good research study —

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the theoretical framework or orientation, the methodological framework, and the guiding research questions — and examines the process by which the choice of a theoretical framework is made.

Fundamental Assertion about Research Design

There is general agreement among individuals who teach graduate courses on educational research that a good Ph.D. dissertation proposal contains three fundamental components: a theoretical framework upon which the study will be built; guiding research questions that the study will try to answer that are consistent with the theoretical framework; and a methodology that is appropriate for probing the guiding research questions. Although this is the order in which these components might be described in a dissertation proposal, it isn't the order in which the elements are generated. The first step toward a research proposal often involves the construction of a draft of the guiding research questions, which will be discussed in the next section.

Guiding Research Questions

The most fundamental assertion about guiding research questions is also the most obvious: It is difficult to find answers to questions you don't ask. You can't base a study on the assumption that you'll just "observe what happens." It is also important to recognize that a given study is a single slice through a lifetime of research, and the individual designing the study will be lucky to make progress toward answering two or perhaps three well-crafted questions within the course of that study.

Research questions not only can but should evolve over the course of a study. Indeed, our experience suggests that when changes do not arise in the research questions during the course of a study, we've probably not asked the right question. To illustrate how research questions evolve during a study, let's look at the work of David Gardner, whose Ph.D. dissertation was entitled "Learning in Quantum Mechanics" (Gardner, 2002). In his dissertation, Gardner notes that his original question was "How do students learn quantum mechanics?" He then points out that preliminary data suggested that the answer was "not very well." Unfortunately, this answer provided no insight into the problems students encounter with quantum mechanics or how to correct them. The guiding research question was, therefore, refined and narrowed as the study evolved.

With time, his work became directed by three questions. The first question — "*What are the experiences of students learning quantum mechanics*?" — came from one of the theoretical frameworks for his study: phenomenography. The second question — "*What conceptual difficulties do students have with quantum mechanics*?" — came from the other theoretical framework: constructivism. The third question — "*How do students approach learning quantum mechanics?*" — is consistent with both theoretical frameworks for the study, but arose as a result of interpretations of the data as it was being collected, which indicated that many of the students' problems with quantum mechanics were the result of inappropriate strategies they used for studying and doing homework. They were not the result of difficulties with the concepts of quantum mechanics (Gardner & Bodner, in press).

Useful insight into the construction of research questions is provided on the website for the *Annals of Research in Engineering Education* (AREE, 2006). Smith (2006) has noted that this organization was created "to engage the engineering-education research community in a consensus-seeking conversation about the nature of high-quality engineering-education research." When last accessed, this website contained a set of guidelines for reflective essays that included the following guidelines for research questions.

- What research question did you start with?
- How did the research questions develop?
- What allowed you to see the opportunity for this research project?
- How did the questions change as you designed and implemented the research?
- What were the final research questions you investigated?
- To whom is the question significant and why?

The Choice of Methodology

Ten years ago, an article with the title "Cancer Undefeated" appeared in *The New England Journal of Medicine* (Bailar & Gornik, 1997). This paper was a response to the call for ways to measure progress against cancer (National Cancer Institute, 1990). The approach to answering this call taken by Bailar and Gornik was based on an analysis of age-adjusted mortality rates due to cancer from 1950 through 1994 because they argued that it "focuses attention on the outcome that is most reliably reported" (p. 1569). An earlier article (Bailar & Smith, 1986) had concluded that "35 years of intense effort ... must be judged a qualified failure" (p. 1230). Bailar and Gornik concluded that "with 12 more years of data and experience, we see little reason to change that conclusion ... " (p. 1573).

As noted elsewhere (Bodner, MacIsaac, & White, 1999), the work of Bailar and Gornick provides a metaphor on which discussions of the choice of methodology for a research study can be based because it illustrates the effect that this choice can have on the conclusions reached in the study. There is reason to believe that different conclusions might have been reached, for example, if Bailar and Gornik had chosen to examine other forms of progress against cancer that are more difficult to quantitate, such as changes in the quality of life after cancer has been diagnosed.

Quantitative Research

Twenty years ago, graduate students involved in educational research began their introduction to research by taking at least two courses in statistics. They then went on to take a course on research design that was often based on the book by Campbell and Stanley (1963), which originally appeared as a chapter in the first edition of the *Handbook of Research on Teaching* (Gage, 1963). This work summarized the classic experimental/control approach to research design and, in general, probed ways in which experimental design could be made more scientific, more quantitative, and more objective. When circumstances precluded the design of a true "experimental" study, Campbell and Stanley suggested ways in which it could become at least "quasi-experimental." The experimental or quasi-experimental approach to research design endorsed by Campbell and Stanley is still in use today; a new version of this classic text was published several years ago (Shadish, Cook, & Campbell, 2002).

Any discussion of the choice of research methodology should start by recognizing that there is nothing inherently wrong with traditional statistics-based quantitative research. But, then again, there is nothing inherently right about quantitative research, either.

Quantitative work isn't intrinsically better, or worse. As Patton (2002) notes, some questions lend themselves to quantitative techniques; others can only be answered using qualitative methods. Patton (2002) raises an interesting point, however, when he argues that quantitative research gives answers to questions of *more* — which class learns *more* material, which approach leads to the retention of *more* students or helps students retain *more* information. Qualitative research provides answers to questions of *better* — do PChem students make *better* decisions about the way they study quantum mechanics?; do organic chemistry students exhibit a *better* understanding of the arrow-pushing formalism?; and so on.

Proponents of quantitative methods are likely to agree with Patton (2002), who noted that quantitative methods are "succinct, parsimonious, and easily aggregated for analysis; quantitative data are systematic, standardized, and easily presented in a short space" (p. 20). And yet, there are potential problems with quantitative research. It tends to focus on the average student and can lead to erroneous conclusions if the change being studied benefits some students and not others. It is often atheoretical — as opposed to qualitative research, which is based on an explicit theoretical perspective. By its very nature, quantitative research focuses on things that can be measured quantitatively, such as student performance on exams, which are often influenced by so many confounding variables it is difficult to tease out the effect for which one is looking. When the sample size is large, one can obtain results that are statistically significant, but not necessarily important. When the sample size is small, one often gets no statistically significant difference, even when there is anecdotal evidence that an effect exists.

For some, quantitative research is better because it is based on “cold,” “hard,” “objective” data. Namenwirth (1986), however, has questioned the myth of the objective scientist.

> Scientists are no more protected from political and cultural influence than other citizens. By draping their scientific activities in claims of neutrality, detachment, and objectivity, scientists augment the perceived importance of their views, absolve themselves of social responsibility for the applications of their work, and leave their (unconscious) minds wide open to political and cultural assumptions. ... while scientists firmly believe that as long as they are not *conscious* of any bias or political agenda, they are neutral and objective, ... in fact they are only unconscious. (p. 29)

To illustrate the effect of the choice of methodology on research results, let’s examine just one of many possible examples. Treagust, Harrison, and Venville (1996) studied the effect of using analogies to teach students. They found that there was no difference in the quantitative achievement scores on a traditional exam on optics for students who had been taught with analogies and those who had not. If this had been their only source of data, they might have concluded that the use of analogies had no effect on the learning of optics. They combined their analysis of exam scores, however, with qualitative interviews that showed that students who had been taught with analogies were able to demonstrate a higher level of conceptual understanding than those who were not.

Shift in Educational Research

Although the chapter on experimental and quasi-experimental designs by Campbell and Stanley appeared in the first edition of the *Handbook of Research on Teaching* in 1963, a similar chapter did not appear in either the second (Travers, 1973) or the third editions (Wittrock, 1986) of that book. This can be taken as evidence for a gradual shift in the way educational research is designed and carried out. In the *Handbook of Research Design in Mathematics*, Lesh and Kelly (2000) describe this shift as moving away from assumptions of “objectivity”; from viewing the student as a lone, passive learner; from relying on simple correlational models; and from relying on one-time measures of achievement such as standardized tests. They advocate moving toward viewing the researcher as a participant-observer who practices self-reflexivity; toward viewing the learner both as an individual and as a social learner in a complex classroom environment; and toward collecting thick, ethnographic descriptions that recognize the theory-ladenness of observation.

Qualitative Methodology

Patton (2002) argues that:

> Qualitative data describe. They take us, as readers, into the time and place of the observation so that we know what it was like to have been there. They capture and communicate someone else's experience of the world in his or her own words. Qualitative data tell a story. (p. 47)

Schwandt (2001) notes that the term *qualitative* is a “not-so-descriptive adjective” attached to various methods of scholarly inquiry that rely on data in the form of words, as opposed to quantitative techniques that generate a product expressible in numbers. The primary sources of data for qualitative research are in-depth, open-ended interviews or “think-aloud” problem-solving sessions; artifacts of the interview process — which consist of drawings, equations, calculations, or ideas jotted down by the subject of the interview during the interview session; field notes taken during observations of classes or during interviews the researcher has conducted; and written documents in the form of reflective journals.

Qualitative research sacrifices the “objectivity” that results from rigid statistical research designs for a combination of flexibility, depth, and detail. The flexibility of qualitative research was captured by Lincoln and Guba (1985) who argued that “ ... the design of naturalistic inquiry ... *cannot* be given in advance; it must emerge, develop, unfold” (p. 225). The depth and detail that are characteristic of qualitative research were captured by Geertz (1973), who noted that qualitative studies produce rich, detailed descriptions of people and places — which he called “thick descriptions” — that enable readers to interpret for themselves the meaning and significance of the research.

Qualitative research is done by individuals with a preference for inductive, hypothesis-generating research, rather than hypothesis-testing research (Glaser & Strauss, 1967). This approach to research, in which one approaches the study with no predetermined hypothesis in mind, is often referred to as “grounded theory” (Charmaz, 2000; Strauss & Corbin, 1990; Taylor & Bogdan, 1998). The increasing number of books devoted to qualitative research methods is testament to the growth in the popularity of this technique (see, for example, Creswell, 1998; Denzin & Lincoln, 1998a, 1998b, 2000; Flick, 2002; Hatch, 2003; Huberman & Miles, 2002; Merriam, 1998; Silverman, 2000, 2001; ten Have, 2004; Yin, 2002).

Mixed Methods for Educational Research

In the late 1970's, most of the papers presented at meetings of the *National Association for Research in Science Teaching* were based on quantitative research designs. The 1980's, however, were a period of the “paradigm wars” (Gage, 1989), during which proponents of the traditional, quantitative, experimental or quasi-experimental paradigm fought pitched battles with advocates of a naturalistic, qualitative approach to research.

At the height of the paradigm wars, it was common to encounter individuals who argued that one had to choose between quantitative and qualitative techniques; that the two techniques could not be combined in a single study. Patton (2002) questions this attitude and argues that qualitative and quantitative methods “constitute alternative, but not mutually exclusive, strategies for research” (p.14). Evidence that the paradigm wars may have ended is the appearance of books that explicitly describe combining qualitative and quantitative approaches (Tashakkori & Teddlie, 1998, 2003) and the *User-Friendly Handbook for Mixed Method Evaluations* that can be found on the NSF web site (NSF, 1997). An example of a study in which classic statistical techniques were combined with qualitative data can be found in the study of the epistemic development of chemistry students and research chemists by Samarapungavan, Westby and Bodner (2006).

Bricolage

Even better evidence of the end of the paradigm wars is the emergence of an approach to educational research described as bricolage (pronounced “bree-koh-LAHZH”). Academic interest in bricolage can be traced back to the work of Lévi-Strauss (1966) for whom a bricoleur might best be defined as a handyman; someone who could make do with what is at hand. Whereas the terms “handyman” and “jack of all trades” are often used in a pejorative sense in English, the terms “bricolage” and “bricoleur” do not carry a similar negative, derogatory or uncomplimentary meaning in French.

The term *bricolage* has been used across a broad spectrum of academic disciplines, including evolutionary biology and genetics (Wilkins, 1998), technology entrepreneurship (Garud & Karnøe, 2003), and design (Büscher, Gill, Mogensen, & Shapiro, 2001; Louridas, 1999). Bricolage involves the construction of something by using whatever materials happen to be available. Strasser (1999) captured the essence of the term when she defined cooking with leftovers as a form of bricolage, “ ... a dialogue between the cook and the available materials.”

A bricoleur is someone who is creative and resourceful, who puts things together in ways for which they might not have originally been designed. When applied to educational research, bricolage implies “ ... complex, multimethodological, multitheoretical forms of inquiry” that focus on “ ... webs of relationships instead of simply things-in-themselves ... ” (Kincheloe, 2005). In many ways, bricolage is an extension of our current methodologies for educational research, focusing on the value of bringing together diverse approaches to this research, using the appropriate methodological tool-at-hand, or even tools-at-hand, to answer a particular research question.

Action Research

A few years ago, we published a paper on Action Research that began as follows (Bodner et al., 1999): “Each time we make significant changes in what we teach or how we teach we are faced with the same question: How can we find out whether the innovation we have brought into our classroom is worthwhile?” (p. 31). One of the advantages of learning how to do educational research is the opportunity to master some of the techniques needed to answer questions such as this.

Chemists have traditionally assumed that the best way to address these questions is to compare student performance on a common exam for an experimental versus control group. Bodner et al (1999) described this as the “sports-mentality approach,” which assumes that one can easily determine the “winner” when different approaches to instruction are compared.

There are three mistakes in the sports-mentality approach to program evaluation. First, and perhaps foremost, it assumes that assessment and evaluation are synonyms. Decisions on the efficacy of a program (evaluation) are therefore based solely on measures of student achievement (assessment). Second, the data collected seldom address the question being asked. As we have noted elsewhere (Bodner et al., 1999), this approach fails to measure differences in *what* is learned; what knowledge is *retained*; or whether there is a difference between the extent to which knowledge we *value* is gained, rather than knowledge that can be easily tested. Potentially erroneous conclusions are therefore obtained from preliminary experiments because this approach presumes that the new instructional material or technique will do better the first time it is used.

Action Research is based on the assumption that any significant change in instruction will have an effect. Whereas the traditional experiment presumes that the change being made either benefits students or it does not, Action Research assumes that some students will benefit from the change, while others will not. It therefore allows one to target a change toward a particular group of students, e.g., the “C” students in one case, the “B” students in another.

Action Research is a cyclic process, in which a change is made, the effect of the change is studied, and modifications are made with the goal of increasing the positive effects and minimizing any negative effects on the target population. Questions that lie at the heart of Action Research methodology include: What is the effect of this intervention? What happens to the teacher? What happens to the students? What components of the intervention are responsible for the positive effects observed? Is there any way to change the intervention to get an even larger positive effect? What components of the intervention gave rise to the negative effects? Is there any way to minimize these effects?

We have described Action Research as an informal, qualitative, formative, subjective, interpretive, reflective, and experiential model of inquiry in which all individuals involved in the study are knowing and contributing participants (Bodner et al., 1999). There are no hidden controls or preemption of direction by the researcher. All participants in the project — students, teachers, and researchers — contribute to the selection of intervention strategies.

There are four fundamental stages in an Action Research cyclic: Plan, Action, Monitoring, and Revised Plan. The cycle starts with the development of an understanding of the problem and the creation of plans for some form of intervention. The intervention is then carried out. Pertinent observations are then collected in various forms. The data are then examined for trends and new strategies are developed that are carried out. The cyclic process is repeated until a sufficient understanding — or implementable solution for — the problem is achieved.

Whereas traditional quantitative approaches to research or program evaluation withhold the innovation from half of the population in the hope that statistical evidence for its efficacy will arise during the course of the study, Action Research assumes that the innovation will have an effect, and tries to maximize its benefits and minimize its disadvantages (Bodner et al., 1999).

Constructivists (see Chapter 2) have argued that knowledge is the result of *reflection on action*; Action Research can be described as *reflection in action*. Reflection on experience is used to generate models, which are used to frame a problem. Intervention strategies are then implemented, which have inevitable consequences that are subjected to further analysis (Bodner et al., 1999).

Theoretical Perspectives or Frameworks

Kuhn (1970) differentiated between research that is based on a paradigm and that which is not. He argued that the use of paradigms makes research more effective by helping researchers select problems that can be solved and by suggesting appropriate methods for collecting data to solve these problems. In educational research, the theoretical framework serves a similar function. It provides the assumptions that guide the research, helps the researcher choose appropriate questions for a given study, and directs the researcher toward data collection methods that are appropriate for the study.

Those who are learning how to do educational research face two major challenges. They must first try to understand some of the theoretical perspectives on which they might base their research. They then have to decide which of these frameworks are inappropriate for addressing the questions they want to answer and select the theoretical framework(s) that is (are) appropriate.

The first reference given to anyone who comes to the author for advice on research design is the book on qualitative research by Patton (1990, 2002), which provides brief descriptions of a variety of theoretical frameworks or orientations such as those listed in Table 1. This book contains chapters on theoretical frameworks that are not explicitly mentioned in Patton's book and excludes some of frameworks he describes because of our emphasis on research design that informs chemistry or science education.

Table 1: Examples of Theoretical Frameworks for Research and Evaluation, based in part on Patton (2002)

Autoethnography: Insights that can be extracted from analysis of one's own experiences.

Constructivism: Focuses on individuals making sense of their experiences.

Critical Theory: Overcoming the uneven balance of power between groups of individuals.

Ethnography: The study of the culture of a group.

Ethnomethodology: The study of people making sense of their experiences to behave in socially acceptable ways.

Feminism: An example of an “orientational” inquiry theory that seeks to understand women’s perception of a phenomenon.

Grounded Theory: Analysis of fieldwork that is used to generate a theory.

Hermeneutics: Providing a voice to individuals or groups who either cannot speak for themselves or are traditionally ignored.

Narratology: Analysis of a narrative or story to reveal something about the world from which the individual comes.

Phenomenology: The search for the common thread or essence of a shared experience.

Phenomenography: The description of different ways people interpret shared experiences.

Positivist/Realist/Analytic Approaches: The search for the “truth” about the real world, insofar as we can get at it.

Pragmatism: Answering practical questions that are not theory-based.

Symbolic Interactionism: The search for a common set of meanings that emerge from interactions within a group.

Systems Theory: Analysis of a system, not the individuals who comprise the system.

The remaining chapters in this book are devoted to a more detailed, in-depth look at some of the theoretical perspectives that either have been or could be applied to educational research in chemistry and science education. We have divided these frameworks into three general categories, as shown in Figure 1. The first category includes theoretical frameworks that can be tied to the constructivist theory of knowledge (Bodner, 1986), the second category includes theoretical perspectives linked to hermeneutics, and the third category groups frameworks or perspectives related to critical theory.

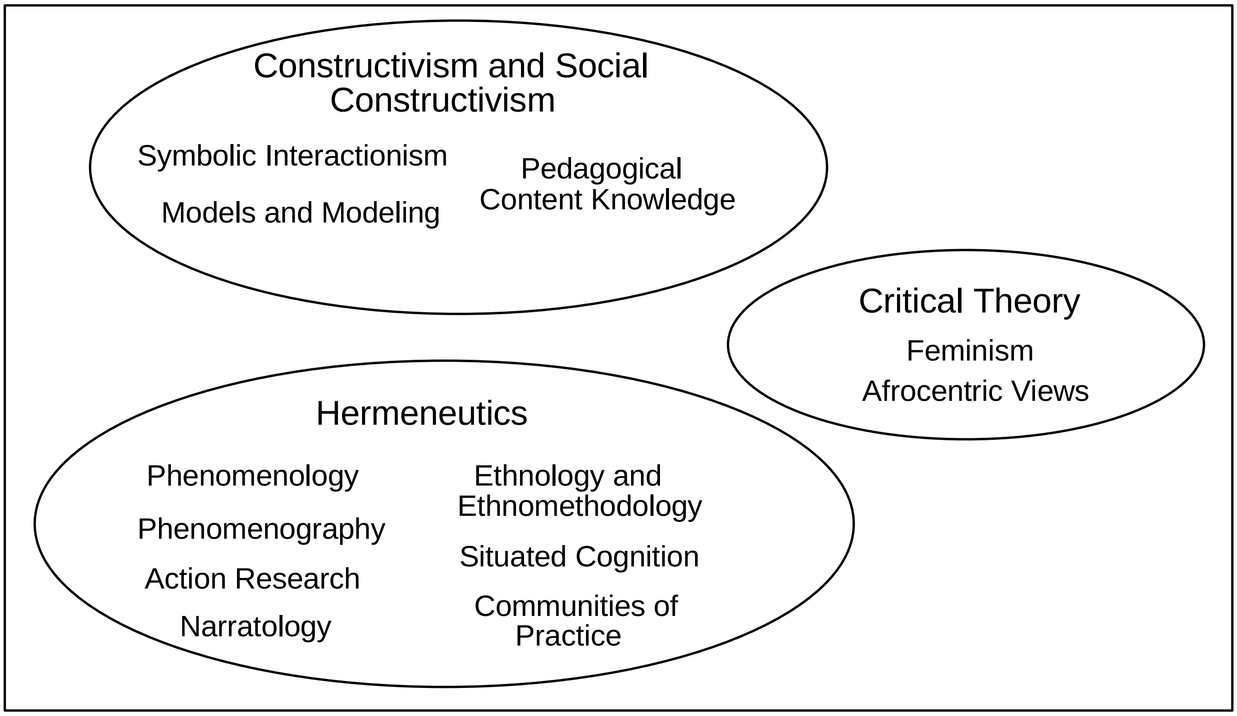

Figure 1. Theoretical perspectives for research in chemistry/science education grouped into categories of constructivism, hermeneutics and critical theory

As the authors of the individual chapters in this book will attempt to show, certain theoretical frameworks are better suited to particular kinds of guiding research questions. Ferguson argues in Chapter 2, for example, that constructivism provides a useful framework for studies that concentrate on meaning-making, on how students come to know. In Chapter 5, Miller describes how pedagogical content knowledge can be used as a theoretical framework to probe the knowledge that teachers bring to the classroom.

Each of the theoretical frameworks also have inherent limitations that can have an effect on their suitability for a particular study. As Bhattacharyya notes in Chapter 10, ethnography and ethnomethodology have been criticized as trying to be too neutral, whereas Mayo points out in Chapter 13 that critical theory has been criticized for not being neutral enough.

Some of the theoretical perspectives in Table 1 are incompatible, but others are not. Thus, there is nothing inherently wrong in having more than one theoretical perspective for a long-term research project, or even for a particular study within that project.

You don’t have to accept all of the assumptions of a given theoretical framework, as it is described by various authors, when you apply it to a study. But you need to be explicit about which assumptions are applicable to a given study.

It is also important to accept the notion that Patton (2002) argues for so cogently: some studies simply are not theory-based because they “involve asking open-ended questions of people and observing matters of interest in real-world settings in order to solve problems, improve programs, or develop policies” (p. 136).

Examples of Theoretical Perspectives

Conversations with colleagues who teach research methods courses have suggested that there are relatively few places to which you can refer beginning researchers to help them choose an appropriate theoretical perspective (Atkinson, Delamont, & Hammersley, 1988; Crotty, 1998; Jacob, 1987; Patton, 2002). There was, therefore, support for the notion of an article (Bodner, 2004) or even a book, such as this one, which describes a handful of popular theoretical perspectives. The order in which these theoretical perspectives are discussed in the remainder of this chapter is somewhat arbitrary, and, in most cases, more than one study from our group could be used to illustrate a given perspective.

Constructivism

The theoretical framework known as constructivism (Chapter 2) can be summarized as follows: “knowledge is constructed in the mind of the learner” (Bodner, 1986, p. 873; see also, Bodner, Klobuchar, & Geelan, 2001; Matthews, 1998; O’Loughlin, 1992; Solomon, 1987; Steffe & Gale, 1995; Tobin, 1993; von Glasersfeld, 1984, 1995). This theoretical framework assumes that we don’t “discover” existing knowledge; we actively construct it. We invent concepts and models to make sense of our experiences and then continually test and modify these constructions in the light of new experiences.

In his first paper on constructivism (Bodner, 1986), the author focused on a view of this theory of learning that has become known as *personal constructivism*, which concentrates on the individual knower and acts of cognition. In that paper, he traced the evolution of constructivism back to the work of Jean Piaget and described a version of this theory known as *radical constructivism*. A second paper described an alternative form of personal constructivism that arose from the work of the clinical psychologist George Kelly and introduced another form of constructivism known as *social constructivism*, which focuses on social interactions that explain how members of a group come to share an understanding of specific life circumstances (Bodner et al., 2001).

It is tempting to think about radical constructivism (von Glasersfeld, 1984, 1995) and social constructivism (Solomon, 1987; O’Loughlin, 1992) as opposite ends of a continuum. At one end, learners construct knowledge in isolation, based on their experiences of the world in which they live. At the other end, learning is embedded in social and cultural factors. Most situations in which learning occurs, however, fall somewhere between these two extremes. Learning is a complex process that occurs within a social context, as the social constructivists point out, but it is ultimately the individual who does the learning, as the radical constructivists would argue.

Research studies based on the constructivist theory often examine the process by which an individual makes sense of their experiences. Research design in this area is guided by the assumption that studies of "sense-making" involve more than just collecting observations. Schwandt (2001) offers the example of the phenomenon of raising one's right hand above one's shoulder as performed by someone hailing a cab, by a student volunteering to answer a question in class, and by a witness testifying in court. In each instance, the same physical phenomenon is observed, but the meaning of the action is fundamentally different. The only way to make sense of the observation would be to talk to the individual.

Symbolic Interactionism

The theoretical perspective known as symbolic interactionism (Chapter 3) comes to us from social psychology. This framework is based on four assumptions: (1) that we act toward the objects and individuals in our environment on the basis of the meaning these objects and individuals have for us; (2) that these meanings are not determined by an individual's experiences; they are the result of social interactions among individuals; (3) that meanings are created and modified through an interpretative process undertaken by an individual member of the group; and (4) that it is these constantly evolving meanings that determine people's actions (Blumer, 1969; Denzin, 1969; Gallant & Kleinman, 1983; Schwandt, 1997).

The term *symbolic* reflects the idea that we communicate through language that is, itself, symbolic. The term *interactionism* emphasizes the role that social interactions have in the construction of knowledge and conceptual understanding. The main goal of the symbolic interactionism researcher is to use observable interactions to identify implied symbolic behavior (Denzin, 1969). Researchers who bring a symbolic interactionist framework to a particular study have to actively enter the setting of the people being studied to see their particular definition of the situation, what they take into account, and how they interpret this information. To understand the process of meaning-making, the researcher must carefully attend to the overt behaviors, speech, and particular circumstances of behavior in the setting in which interactions take place.

Symbolic interactionism assumes that the researcher must view things through the perspective of those under study. As a result, participant observation becomes a key method here; it allows the researcher to place the data being collected into the context of the operating classroom and to participate in the interactions between and among the subjects.

Del Carlo and Bodner (2004) used symbolic interactionism to study the ethical philosophies — the "objects" in symbolic interactionist terms — students develop through interactions with other students, research advisors, professors, or TA's in the laboratory setting. This argued that interactions within the classroom lab environment play an important part in the evolution of meanings for the individuals involved in the interaction. This meant that the data on which this study was based had to consist of both observations of actions in the laboratory environment and in-depth interviews outside of the classroom that were designed to uncover individual meanings.

Hermeneutics

The term *hermeneutics* (Chapter 6) is often traced back to “Hermes,” the messenger of the gods in Greek mythology. Hermes not only delivered decrees from Mount Olympus, he interpreted for humans the meaning and intention of the messages he brought (Polkinghorne, 1983). Hermes has, therefore, been described as the guide to intelligent speech (Parada, 1993), and the Greek word *hermeneuein* is translated as “to interpret.” Hermeneutics has been described as “the art, theory and philosophy of interpreting the meaning of an object (a text, a work of art, social action, the utterances of another speaker, etc.)” (Schwandt, 2001, p. 115). Schleiermacher (1997) argued that hermeneutics is necessary when there is the chance of misunderstanding the meaning of the object. The development of hermeneutics began in the period after the Renaissance, when the principles of interpretation of text were applied to the study of sacred (biblical) texts and texts from classical antiquity (Polkinghorne, 1983). Dilthy (1976) expanded the scope of hermeneutics by raising the question: If the techniques of hermeneutics could be used to systematically interpret written texts, why not apply them to speeches, conversations, or interviews or even to the “text” of a person’s life or experiences?

An important feature of hermeneutics is the notion of the hermeneutic “circle” or “spiral.” In order to understand the meaning of a text, the interpreter needs to understand its parts; and yet, in order to understand the different parts of a text, the interpreter needs to understand the whole text. The first interpretation of the text is based on the prior knowledge the researcher brings to the text, but this prior knowledge is changed by reading the text. As a result, the researcher brings a different perspective to the second reading, which changes the knowledge the researcher brings to a third reading, and so on, *ad infinitum*. In practice, however, there is a point at which further readings do not substantively change one’s understanding.

Hermeneutics is often used in educational research in the sense of providing a “voice” to those who either cannot speak for themselves or who have not been listened to. It was, therefore, an appropriate framework for a study conducted by Hunter, in which he looked at what happens when “discovery” labs are integrated into the curriculum at a large research university (Bodner, Hunter, & Lamba, 1998).

Phenomenology and Phenomenography

Suppose that you were familiar with the structure of a typical organic chemistry course. You knew something about the subject matter covered, the kind of textbooks used, the way the course was usually taught, the kind of questions that were likely to appear on exams, and so on. You would have what is called a first-order understanding of the phenomenon of organic chemistry courses. Now, suppose that you were interested in understanding what it means from the students’ perspective to “take” organic chemistry. Your goal would be a second-order perspective — an understanding of the students' experience with the course, not your own. The traditional paradigm that guides research designed to understand the meaning of human experience is known as *phenomenology* (Marton, 1996; Sokolowski, 2000; van Manen, 1990).

Phenomenology (Chapter 7) is based on the work of philosophers such as Husserl, Schutz, Merleau-Ponty, Gadamer, and Ricoeur (Polkinghorne, 1983). The characteristics of phenomenology might best be described by paraphrasing the comments of van Manen (1990). He defines phenomenology as the study of the world as we experience it, not as we conceptualize or reflect on it. The goal of phenomenology is "a deeper understanding of the nature or meaning of everyday experiences" (p. 9). The focus is on the lived experiences while they are being lived, not after one reflects on them. Phenomenology searches for the "essence" of a phenomenon, the "something" that makes the phenomenon what it is, the "something" without which the phenomenon could not be what it is.

The term *phenomenology* has been used by many researchers to describe studies that don't quite fit the classic definition. Studies that don't assume that "essence" is singular; that don't assume there is a common thread that describes the meaning of the experience for everyone who lives it. Our group has, therefore, been quite careful to differentiate between traditional approaches based on phenomenology and those that look similar but are based on a slightly different perspective known as *phenomenography* (Marton, 1986; Marton, Hounsell & Entwistle, 1997).

The focus of phenomenography (Chapter 8) is still on the meaning of an experience. The goal of phenomenography is to understand how people experience, interpret, understand, perceive, and conceptualize a phenomenon (Orgill, 2003). Phenomenography assumes that knowledge results from thinking about experiences with people and objects in the world in which we live.

Whereas phenomenology looks for the common essence that characterizes the phenomenon for all who experience it, phenomenography assumes that people can and will experience the same phenomenon in a limited number of ways that are qualitatively different (Säljö, 1997). Marton (1981) captures the essence of phenomenography by noting that it searches for the middle ground between the extremes of "the common" and "the idiosyncratic."

The goal of phenomenography is to understand the phenomenon from the participant's point of view. The researcher therefore tries to act as a "neutral foil" for the ideas expressed by the participants of the study. This does not mean, however, that the researcher is an objective observer akin to a video camera (Lowrey, 2002). In the course of an interview, the researcher's knowledge may be used to help the participants better explain what they mean. Entwistle (1997) argues that richer descriptions can be obtained when the interviewer contributes to the effort to explain the student's interpretation of experiences.

Phenomenographers do not claim that the results of their research represent “truth”; only that their results are useful (Svensson, 1997). Marton (1994) noted that it isn’t important whether the participant’s conceptions are viewed as “correct” or “incorrect” by others; the goal of the research is to identify the possible conceptions members of a group have of a given phenomenon.

The primary source of data for phenomenography is an open, intensive interview (Booth, 1997). It is open in the sense that there is no prearranged structure to the interview; it is intensive in the sense that the interview follows a given line of questioning until the participant has nothing more to say. Data analysis begins by having the researcher identify the qualitatively different ways in which different people experience a given concept. One of the potential pitfalls of phenomenography is the tendency to assume that students’ accounts of their experiences are the same as the students’ experiences.

Säljö (1997) notes that there sometimes appears to be a discrepancy between what researchers observe when they watch a participant go through an experience and the way participants describe their experiences. Säljö, therefore, suggests that we refer to studying people’s “accounting practices” of phenomena, instead of referring to studying people’s “experiences.”

There are several ways in which the results of phenomenographic research can be useful. Entwistle (1997) noted that students are generally encouraged to develop a conceptual understanding, and that teachers often try to help their students develop concepts that are consistent with those held by experts in the field. Students, however, often have conceptions of a phenomenon that are not consistent with those held by experts. Marton (1996) claims that “a careful account of the different ways people think about phenomena may help uncover conditions that facilitate the transition from one way of thinking to a qualitatively ‘better’ perception of reality” (p. 33).

Critical Theory

The critical theory movement was founded in 1923 at the *Institut für Sozialforschung* in Frankfurt, Germany. The first generation of critical theorists included Adorno, Marcuse and Fromm; the most influential modern spokesperson for critical theory is Jürgen Habermas (McCarthy, 1979; Roderick, 1986: Young, 1990),

Critical theory (Chapter 14) calls for reasoning that is practical, moral, and ethically and politically informative. The goal is individual and social transformation via self-knowledge. Critical theory rejects the idea that one can have a disinterested observer who contemplates the system from a distance.

Critical theory often focuses on situations where there is an uneven sharing of power. It therefore often involves discussions of “emancipation.” The author endorses the application of critical theory to educational research because of the structure of the traditional teacher-centered classroom, where power lies in the hands of the instructor who decides what is taught (or learned), the order in which it is taught (or learned), the amount of time devoted to a given topic, and so on (Young, 1990).

Habermas talks about technical knowledge (*techné*) and knowledge that comes from one's view of what is right or good (*phronesis*). But he also talks about *emancipatory* knowledge, which literally frees the individual. The author's favorite example of emancipatory knowledge is learning how to ride a bicycle as a child. At that moment, the individual is free. There is no longer the need to ask a parent or adult for help getting somewhere; the individual is free to make decisions about where he or she is going on their own. It therefore isn't surprising that Mayo (2004) chose critical theory as the framework upon which to build a Ph.D. dissertation that examined the impact of figures from chemistry texts on the learning by visually impaired students; students who have historically been excluded from chemistry classrooms and lab courses.

Critical theory seeks a diversified education for all that creates individuals who can think critically. It assumes that schools can become institutions in which knowledge, values, and social relations are taught to educate students for critical empowerment (Giroux, 1988). The ultimate goal of critical theory is a transformation of society into one that is just, rational, and humane.

Ethnography and Ethnomethodology

Ethnography (Schensul & LeCompte, 1999; see also Chapter 10) is often thought of as a methodological framework, but it has strong theoretical aspects. It has its basis in cultural anthropology, where the goal is describing the behavior of a culture on the basis of first-hand experiences with members of that culture through field studies.

A related theoretical framework known as ethnomethodology (Chapter 10) was developed by Garfinkel (1967) as the basis for sociological research. It focuses on how people accomplish the interactions we take for granted in everyday life. Ethnomethodology " ... gets at the norms, understandings, and assumptions that are taken for granted by people in a setting because they are so deeply understood that people don't even think about why they do what they do" (Patton, 2002, p. 111). It is based on descriptive accounts that organize and render observable the features of society and social settings (Leiter, 1980).

Ethnomethodology was chosen as the theoretical perspective for a study of how graduate students learn to solve organic synthesis problems (Bhattacharyya, Calimisiz, & Bodner, 2004). This choice of theoretical perspective was based on the assumption that the community of synthetic organic chemists constitutes a culture to which students become acculturated as their understanding of the field develops. This perspective recognizes that synthetic organic chemists routinely use language that is unique to their community; that a well-trained chemist from another discipline wouldn't be able to participate in a conversation between practicing synthetic chemists unless explicit attempts were made to include that individual in the conversation; and that synthetic organic chemists use tools such as retrosynthetic analysis and the arrow-pushing formalism that are unique to this community.

Conclusion

Readers who have reached this point should not be surprised to find that the noted expert on research design Lee Cronbach (1982) has argued that designing a study is as much an art as it is a science. So far, I have discussed three of the basic pieces of a study: the theoretical framework, the methods of data collection, and the guiding questions. If these pieces form a coherent, unified whole, then so should the data and the data analysis (Crotty, 1998). The theoretical frameworks I have focused on in this chapter are those with which my research group has had the most experience. The remaining chapters of this book are devoted to more detailed descriptions of a variety of theoretical frameworks that either have been used in chemistry and/or science education.

An important point needs to be recognized before the reader proceeds to the discussions of the individual theoretical frameworks that comprise the bulk of this book. In the years since I wrote the first draft of this chapter I have come to realize that I ignored an important element in the design of any educational research study. Educational research does not occur in a three-dimensional world dominated by concerns with the dimensions of guiding research questions, theoretical framework, and methodology. It occurs in a four-dimensional world in which the fourth dimension is the preparation, submission, and eventual approval of the study by an appropriate Institutional Review Board or IRB. Our experience suggests, however, that effort devoted to making decisions about guiding research questions, theoretical framework, and methodology should be compensated for in the ease with which a suitable IRB proposal can be written.

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2

Constructivism and Social Constructivism

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Biography

Robert Ferguson is an Assistant Professor of Science Education at Cleveland State University. After receiving his Bachelor of Arts in Biological Sciences and a teaching credential in Life Science and Chemistry from San José State University he taught high-school science for seven years. Wanting to both learn some chemistry and become a teacher of teachers, he applied for a spot in the Chemical Education program at Purdue University. He accomplished both goals with a M.S. thesis that focused on organic synthesis and a Ph.D. dissertation that studied chemistry majors' understanding of reaction mechanisms. Upon graduation he accepted his current position at Cleveland State University, where he teaches elementary and secondary science methods courses and directs the Northeast Ohio Elementary Science Olympiad.

Introduction

Constructivism is a theory of learning with its origin in the cognitive sciences that eventually was discussed, parsed, and applied in both science education and chemistry education. This chapter starts with a description of the basic tenets of constructivism and its ontological considerations. The history of constructivism as a theoretical framework is then used as the basis for introducing research methodologies associated with constructivism. The chapter then concludes by examining examples of research studies that have used constructivism as a research lens.

A Description of Constructivism

As a theory of learning, constructivism provides a basis for understanding how people incorporate new knowledge into existing knowledge and then make sense of that knowledge (Nussbaum, 1989; Tobin, 1990; von Glasersfeld, 1992). It provides a theoretical framework for thinking about how people engage with objects in the world around them and make sense of these objects (Bodner, 1986; Bodner, Klobuchar, & Geelan, 2001). In the previous chapter, Bodner (2006) argued that constructivism is based on the assumption that people don't "discover" existing knowledge, they actively construct it. He went on to argue that they "invent concepts and models to make sense of their experiences and then continually test and modify these constructions in light of new experiences" (p. 13) According to Fosnot and Perry (2005), the aim of constructivism is "*cognitive development and deep understanding*" (p. 10, italics in the original). Bodner (1986) tried to capture the spirit of the constructivist theory by arguing that "knowledge is constructed in the mind of the learner" (p. 873).

The term constructivism has been applied to a wide range of concepts and ideas with each "form" (Good, 1993) or "brand" (Staver, 1998) having its own tenets, assumptions, and implications. Geelan (1997) reviewed the six most prevalent forms and explained how each form varies in the way it prioritizes the individual learner, the social milieu, the role of language, and the balance of power during the process by which knowledge is constructed. He also associated each of these forms with the individual with whom it was most closely associated.

- Personal constructivism: Kelly and Piaget
- Radical constructivism: von Glasersfeld
- Social constructivism: Solomon
- Critical constructivism: Taylor
- Contextual constructivism: Cobern
- Social constructionism: Gergen

Whereas the five forms of "constructivism" on this list focus on sense-making or meaning-making within the individual, social "constructionism" presumes that knowledge is held collectively within a group or society and that language serves as its mediator (Geelan, 1997). Crotty (1998) provides a distinction between constructivism and contructionism when he argues:

> It would appear useful, then, to reserve the term constructivism for epistemological considerations focusing exclusively on 'the meaning-making activity of the individual mind' and to use the term constructionism where the focus includes 'the collective generation [and transmission] of meaning.' (p. 58)

Both the personal constructivism of Piaget or Kelly (1955) and the radical constructivism advocated by von Glasersfeld focus on the sense-making or meaning-making that occurs as individuals try to understand their experiences with the world in which they live. Within the context of a classroom environment, proponents of personal constructivism might argue that knowledge is never transmitted intact from the instructor to the learner.

Social constructivism was proposed as an alternative to personal constructivism by Solomon (1987) and O'Loughlin (1992). At first glance, one might question how a constructivist theory of knowledge can be called "social" constructivism. However, as Bodner (2006) noted in the previous chapter:

> It is tempting to think about radical constructivism (von Glasersfeld, 1984, 1995) and social constructivism (Solomon, 1987; O'Loughlin, 1992) as opposite ends of a continuum. At one end, learners construct knowledge in isolation, based on their experiences of the world in which they live. At the other end, learning is embedded in social and cultural factors. Most situations in which learning occurs, however, fall somewhere between these two extremes. Learning is a complex process that occurs within a social context, as the social constructivists point out, but it is ultimately the individual who does the learning, as the radical constructivists would argue. (p. 13)

In order to avoid getting bogged down in a debate over social versus personal constructivism, it might be more useful to focus on their commonalities. Clearly, social and personal constructivism share theoretical underpinnings (Marín, Bennaroch, & Jiménez-Gómez, 2000; Staver, 1998). Staver (1998) highlights the common ground by arguing that all forms of constructivism assume that: (1) individuals and communities build up knowledge; (2) social interactions, whether they are individual, social or cultural, play an important role in the construction of knowledge; (3) the learning construction and the language surrounding the knowledge being constructed must be useful, practical, and "adaptive"; and (4) learning and language serve to bring coherency to the individuals' experiences and the knowledge base of the community.

Because the goal of this chapter is to introduce constructivism as a research lens, no form of constructivism will be assumed to be superior to another. For the purposes of this chapter, the use of the term "constructivism" will be assumed to refer to a theoretical framework consistent with the four characteristics outlined by Staver.

The Ontological Assumptions of Constructivism

Bodner, Geelan and Klobuchar (2001) compared differences between traditional and constructivist theories of knowledge to differences between the realist and relativist positions in the philosophy of science. They argued that "realists and relativists agree on one point: our knowledge of the world is based on the experiences of our senses. They differ, however, on their beliefs about the extent to which the world is knowable" (p. 1107)

Von Glasersfeld (1995) has noted that critics have accused proponents of the constructivist theory of denying the existence of "reality." They have even gone so far as to accuse constructivism of solipsism (Martínez-Delgado, 2002), a form of egotism that rejects the existence of everything except the individual. This is not an accurate reflection of the constructivist theory, however. Most constructivists do not question the existence of reality, they only question our ability to *judge* or *know* reality and therefore our ability to judge whether something is “true” or “false” (Tobin, 1990). Staver (1998) rebuffs the critics by noting, “constructivists are sometimes labeled as solipsists because they challenge realists’ wishes, refuse to embrace truth as correspondence, and advise silence on ontology” (p. 506). Constructivists do not deny a reality; they are relativists (Lincoln & Guba, 2000). Constructivism as a theory does not allow the researcher to engage in ontological debates; in terms of ontology the theory is “mute” (Schwandt, 2000).

Von Glasersfeld (1984) argued that traditional theories of knowledge search for a correspondence between knowledge and reality in much the same way that one might match samples of paint; they are either the same or they must be different. The constructivist theory approaches the search for knowledge from the perspective of coherence in the sense of the metaphor of a lock and a key; there can be many keys with slightly different shapes that open the same lock.

From the constructivist perspective, truth is based on coherence with our knowledge not correspondence between knowledge and objective reality (Edmondson & Novak, 1993; Staver, 1998). Constructivists believe that knowledge only exists within us, the cognizant beings. Knowledge is non-confirmable, non-provable, and is not "discovered” (Nussbaum, 1989).

A Brief History of Constructivism

Constructivism did not start as a theoretical framework for doing educational research; it originated as a theory in cognitive science whose goal was to explain the incorporation of knowledge. Because the history of constructivism is somewhat lengthy (see Cobern, 1993), only a brief synopsis is provided here.

Socrates receives credit as the first to articulate the idea of the learner as the builder of knowledge (Nola, 1997). Von Glassersfeld (2005) credits the pioneering work of Piaget in the 1940’s as the beginning of constructivism. Piaget’s contributions stem from his work with the cognitive development of children (Fosnot & Perry, 2005). Specifically, Piaget set forth the key ideas that learning occurs in stages, and that knowledge is organized as cognitive structures (Brooks & Brooks, 1993). Piaget also provided us with the notion that learning occurs through a dynamic interaction between the individual and the environment, and that “knowledge is constantly being constructed and reconstructed from previous and new experiences” (Llewellyn, 2005, p. 36).

Later, as cognitive scientists incorporated the work of Vygotsky (Llewellyn, 2005), constructivism grew to include both a language component and a social interaction component. Vygotsky (1986) believed that social interactions had a strong influence on both how and what an individual learned. He was less concerned about stages in learning than Piaget, but, instead, focused on how a learner was cognitively limited to a zone known as the Zone of Proximal Development. In Vygotsky’s model of the learning process, this zone is bounded on one end by skills or knowledge possessed by the learner and on the other end by skills or knowledge that can only be gained with outside aid (Llewellyn, 2005; Parks, 2001). A situation that is beyond the first boundary lacks any cognitive demand from the learner; the learner either already possesses the skill or understands the concept. If the learner is placed outside the second boundary, the cognitive demand is greater than the capabilities of the learner.

Although theoretical discussions of the constructivism of Piaget, Vygotsky and von Glasersfeld could be found in the science education literature by the middle of the 1980's (Bodner, 1986), science education research received its first look at the implication of von Glasersfeld radical constructivism through the work of Ken Tobin (see Matthews, 2002). In his 1988 article, Tobin and co-workers offered constructivism as a framework to analyze the teaching methods of an exemplary, yet traditional, high-school science teacher (Tobin et al., 1988). Since that time, a plethora of studies have been conducted with constructivism as the theoretical perspective or lens. The bulk of these studies look at employing constructivism as an epistemology in the classroom (see Herron & Nurrenbern, 1999). These studies offer constructivism as a guide to making changes in the curriculum that take the classroom environment away from a traditional teacher-centered, lecture-driven course toward a student-centered, experiential classroom. An example of using constructivism as a curriculum intervention strategy can be seen in the work of van Keulen (1996), who rewrote an ester synthesis experiment for a college-level organic chemistry laboratory class with the goal of minimizing the number of traditional, verification or cookbook laboratories used in the laboratory component of the course.

The Guiding Questions of Constructivism

Researchers contemplating constructivism as a theoretical framework should consider the type of questions for which constructivism is most appropriate. Constructivism is best suited for studies that focus on sense- or meaning-making, concept construction, or elucidation of alternative concepts. Constructivism should be used when the goal of the study is to describe the cognitive structures of the concepts held by the learner (Cobern, 1983).

Constructivism can be used to answer the following types of questions: "How have people in this setting constructed reality? What are the reported perceptions, 'truths' explanations, beliefs, and worldviews? What are the consequences of their constructions for their behavior and for those with whom they interact?" (Patton, 2002, p. 96). Specifically for science and chemical education research, constructivism can be used to ask, " … What is a student's construction of (say) gravity and how does that construction compare with the epistemological truth of science?" (Cobern, 1993, p. 53). Only studies that focus on research questions related to how learners make sense of phenomena should use constructivism as a research lens.

Some examples of chemical education research from a constructivist perspective were based on the following guiding research questions:

- What are the identified alternative conceptions regarding gas, dissolution, and chemical change held by 8th grade Turkish students and student teachers? (Çalik & Ayas, 2005).

- How do secondary students, undergraduates and graduate students employ mental models of their conceptions of bonding? (Coll & Treagust, 2002, 2003).

- What are childrens' (ages 11-14) concepts of substance, melting and boiling and what are their concepts of chemical change with a focus on the use of elements, compounds, and bonding? (Johnson, 2000, 2002)..

- How do students from grade 1 to grade 10 develop their understanding of matter? (Liu & Lesniak, 2006).

- How aware are chemistry instructors of students' alternative conceptions in chemical equilibrium? (Piquette & Heikkinen, 2005).

- When using chemical change phenomena, what are the processes, and characteristics of concept organization? (Stavridou & Solomonidou, 1998).

- What are the patterns found at the intersection of individual and group meaning-making taking place among 3rd graders in the context of an urban school? (Southerland, Kittleson, Settlage, & Lanier, 2005).

Methodologies

The aim of constructivism is "understanding and reconstruction" (Lincoln & Guba, 2000). As with any naturalistic inquiry, the use of the correct methodology is imperative in order to be consistent with the basic tenets of constructivism. Methodology, according to Crotty (1998), is "the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcome" (p. 3). The methodology of data collection used in a study based on constructivism as a research lens needs to be designed to aid in understanding the concepts held by the research participant (or learner) and allow the researcher to reconstruct the cognitive structures with fidelity. Lincoln and Guba (2000) suggested that this methodology must be "hermeneutic and dialectic." The etymological root of hermeneutics (see Chapter 6) stems from the mythical messenger of the Greek gods, Hermes, who brought the message of the gods to the mortals in an understandable form (Crotty, 1998). Research based on a constructivist perspective fulfills a similar role, bringing a message from one audience, the learner or participant, to another audience, the reader.

Webster's New 20th Century Dictionary (1983) defines "dialectic" as the art or practice of examining opinions or ideas logically, often by the method of question and answer, so as to determine their validity. Kemmis and McTaggart (2000) provided additional insight into the meaning of "dialectic" by noting that it includes the act of "… seeing things intersubjectively, from one's own point of view and from the point of view of others (from the inside and the outside)" (p. 574). For the researcher, dialectics describes the process by which one arrives at a common answer or consensus via discussion.

A dialectic methodology includes sharing the control of the conversation or the answer between researcher and participant (Lincoln & Guba, 2000). The dialectic methodology can be seen in an interview where a researcher listens to a participant explain answers to various questions; in a post interview where a researcher shares findings with a participant; in a dialogue between colleagues where the researcher confirms newly emergent themes with a peer; or in co-collaborative conversations during which the researcher and participant mutually interpret data. Through these discussions, the researcher tries to see the world from the perspective of the individual whose sense-making or meaning-making is being studied. The dialectic methodology can therefore be used as part of a variety of research tools, including interviews about instances, interviews about events (see Osborne & Freyburg, 1985), think-aloud protocols (Larkin & Rainard, 1984), and concept maps and other graphical organizers (Novak & Gowin, 1984).

A careful selection of the methods used in a study based on a constructivist perspective enables the participant to produce both artifacts, which demonstrate knowledge, and conversations that build consensus. Methods that align with a hermeneutical and dialectical methodology afford the researcher a glimpse into the conceptions held by the participant. They help illuminate the knowledge that is constructed in the mind of the learner, and thereby align with constructivism as a research lens.

Methods and Analysis

So far, I have argued that constructivism focuses on questions that pertain to meaning-making, sense-making, concept construction, or the elucidation of alternative conceptions. I have also argued that researchers who use constructivism to guide a study should use methodologies for data collection that are both hermeneutic and dialectic. This section provides comments on various examples of design strategies, data sources, data analysis, and validity issues.

Constructivism permeates science education research (Matthews, 2002). Constructivism as an epistemology, constructivism as a theoretical framework, and constructivism as a theory of learning has produced hundreds, if not thousands, of articles, reports and manuscripts. In this section, I have focused on those chemistry-related studies that used hermeneutic and dialectic methodologies (Lincoln & Guba, 2000). Although this literature review is far from exhaustive, the studies presented here provide insight into the key elements in the research based on a constructivist perspective.

Design Strategies

Design strategies that met the selection criteria described above could involve the use of either a purely qualitative methodology or a mixture of qualitative and quantitative data collection techniques. (A purely quantitative approach would not meet the selection criteria because it would not be dialectical.) An example of a mixed-method approach to constructivist research can be found in a study of college-level chemistry instructors approach to teaching chemical equilibrium (Piquette & Heikkinen, 2005). The design strategy included a survey of 52 college and university chemistry instructors using open-ended responses, a four-point Likert scale, a set of mock student responses, and a series of demographic questions. The survey focused on awareness, identification, and strategies of remediation for students with alternative conceptions of chemical equilibrium. Following the analysis of the surveys, six respondents were invited to participate in individual, semi-structured phone interviews. The follow-up interviews allowed the participants to clarify their earlier responses, and provided the researchers with an opportunity to triangulate their data.

Çalik and Ayas (2005) tested 50 eighth-grade students and 50 student teachers from the East Black Sea region of Turkey in order to identify alternative conceptions of gas, dissolution, and chemical change. In their study, Çalik and Ayas placed a greater emphasis than the previously described study on answers to free-response questions, students' presentation of ideas via diagrams, and substantial dialogic exchanges between the students and the researchers. They started their research with a pencil-and-paper test that did not contain either Likert-scale or multiple-choice questions. The students' responses involved either explanations of answers to open-ended questions or the creation of a drawing. After the administration of the paper-and-pencil exam, Çalik and Ayas interviewed small groups of participants using an "interview about events" technique. The interviewers brought two containers to the interview, an open aqueous $NaCO_3$ system and a closed aqueous $NaCO_3$/HCl system. The participants discussed their ideas concerning the concepts of gas, dissolution, and chemical changes initially with their peers, and then with the interviewer. The analysis of the open-ended questions, the participant's drawings, and the transcription of the group interviews exemplified the use of a hermeneutic methodology in this study.

Familiarity with Participants

The work of Piquette and Heikkinen (2005) and Çalik and Ayas (2005) are examples of studies in which the researchers were relatively unfamiliar with the participants, or conversed briefly with the participants. Other approaches to the design of a study are based on a larger degree of familiarity with the participants in the study. Consider the longitudinal study reported by Johnson (2000, 2002), for example, in which 147 children between the ages of 11 and 14 were tracked for three years in an effort to describe their concept of "substance" — specifically their use of the terms *elements*, *compounds*, *bonding*, *melting* and *boiling*. In the course of this study, Johnson periodically interviewed the same 33 students over the course of the three years. The long-term relationship between the researcher and the subjects of this study not only allowed

Johnson to intimately know the curriculum, the teachers, and the students, but it allowed his participants to know him, as well.

Southerland et al. (2005) incorporated discourse analysis in their study of third-graders' understanding of condensation and phase change in order to probe " … the patterns found at the intersection of individual and group meaning making … " (p. 1035). The work of Sutherland, et al., is another example of a research design in which the researchers were familiar with the subjects of the study. Before the lesson on condensation was taught, Settlage had worked with the classroom teacher for three years and co-taught science lessons on a weekly basis in the classroom. The students were therefore accustomed to his presence in the classroom and his constructivistic pedagogy. Settlage's consistent, long-term interactions with students provided the researchers with a deeper knowledge of the context in which data were collected.

Data Sources

Data sources for studies of meaning-making can include interviews and/or artifact production. Interviews and artifact production can occur simultaneously or independently, and one of these data sources can lead to the other. Interviews are a rich, primary source of data. Reported methods of interviewing go beyond the semi-structured interview to include think-aloud protocols, interviews about instances, and interviews about events.

Think-aloud protocols (Larkin & Raindard, 1984) involve the participant solving a problem. Bowen (1990), for example, used a think-aloud protocol to explore what graduate students considered as they solved synthesis problems in organic chemistry.

In studies that use the interview-about-instance (IAI) technique, the interviewer offers the participant a choice in a particular situation. For example, Stavridou and Solomonidou (1998) gave their participants cards featuring a physical or chemical change and then asked their participants to identify those examples of chemical change.

In the interview-about-events (IAE) approach to data collection, the phenomenon is dynamic. In an IAE, a series of events are displayed or demonstrated to the participants, who are asked to describe their observations, and provide an explanation of what they have observed. Coll & Treagust (2002, 2003), for example, had each participant view a drawing on a card of the formation of a copper ammonium complex, observe a demonstration of the complex-formation reaction, and then explain the process they observed.

Researchers can use think-aloud protocols and either interview-about-instance or interview-about-events approaches to "deliberately activate" concepts (Stavridou & Solomonidou, 1998). Each of these interview methods is designed to stimulate dialogue and engage the participant in a conversation.

Valanides, Nicolaidou, and Eilks (2003) employed a variation of the interview-about-events technique. Their data were collected in a high-school chemistry classroom where nine 12th-grade Cypriot chemistry students predicted, performed, and explained what happened when a piece of copper wire or a piece magnesium strip was heated with a Bunsen burner. This study used a traditional chemistry experiment as a prompt to explore understanding about oxidation-reduction reactions. The interviews included questions about macroscopic and microscopic changes associated with the reactions. Participants were also provided opportunities to discuss any inconsistencies between their pre-experimental predictions and post-experimental explanations.

Another source of data is artifact production; the production of something that is both physical and tangible. Having participants produce artifacts is neither separate from nor exclusive to interviews; interviews and artifact production can be used in tandem, if not synergistically. Using the interview-about-events technique, for example, produces dialogue and drawings (see Coll & Treagust, 2002, 2003). Artifacts include but are not limited to drawings (Çalik & Ayas, 2005; Coll & Treagust, 2002, 2003; Ferguson, 2003); models (Nicoll, 2003); and concept maps (Novak & Gowin, 1984).

Excellent examples of drawings-as-artifacts can be seen in the movies, “Minds of our Own” (Schneps, 1997), and “A Private Universe” (Schneps, 1987). These videos demonstrate the power of having the participant draw and explain their conceptions of the cause of the seasons, electrical circuits, or photosynthesis. These videos also provide good examples of the conversational exchange (or dialectic) between the interviewer and the participant and the production of the drawing or the artifact by allowing the viewer to see the different conceptions of the participants unfold during the interview.

Asking the participant to create models allows the participant to describe phenomena in three dimensions. For example, Nicoll (2003) interviewed 56 college chemistry majors with the objective “ … to determine how students conceived of the submicroscopic world and whether these conceptions changed over increasing chemistry instruction … ” (p. 205). During the semi-structured interviews, she gave the participants two tasks: (1) draw the Lewis structure of formaldehyde, and (2) build the Lewis structure using modeling clay (Play-doh). The clay structures helped to elucidate the participants’ concept of molecular geometry by augmenting the verbal descriptions and the 2-D drawing in the Lewis structure of the molecular geometry.

Various graphical organizers have been used to study understanding, meaning-making, and alternative conceptions in chemistry, but few are as prevalent as concept maps (Novak & Gowin, 1984). Many examples of the use of concept maps to probe understanding in chemistry can be found in the literature (e.g., Markow & Lonning, 1998; Nakhleh, 1994; Nakhleh & Krajcik, 1994; Nicoll, Francisco, & Nakhleh, 2001b; Pendley, Bretz, & Novak, 1994; Regis, Aberttazzi, & Roletto, 1996; Stensvold & Wilson, 1990). The work of Nicoll et al. (2001b), however, exemplifies the use of concept maps as a means of expressing conceptual understanding. Nicoll et al. (2001b) explored the effect concept maps had on students' ability to organize several chemistry topics: bonding, electronegativity, electrons, and molecular structure.

Data Analysis and Interpretation

Once the artifacts have been collected, and the interview is completed, the recording of the interview is transcribed to produce a text of the conversation. Grounded theory (Strauss & Corbin, 1994, 1998) is then used as a data analysis technique to develop descriptions of the participants' concepts. This inductive approach, also known as a *constant comparison method* (Patton, 2002), is more cyclic than linear. The process of data analysis consists of three deceptively simple phases: data collection, coding, and memoing. In grounded theory, the researcher moves back and forth between these three phases. Initially, the researcher will spend more time in the data-collection phase (interviews and artifact production). As the study progresses, the researcher will dedicate more time to the coding and memoing phases.

Strauss (1987) described coding as provisionally conceptualizing the data and producing categories and subcategories. These coding schemes are, by design, meant to be tentative and malleable or even disposable. According to Strauss and Corbin (1994), this coding act produces insight for the researchers and sends them back to collect more data, until such a time that further data collection produces no new insights. Strauss and Corbin (1998) defined memoing (or the act of making memos) as "the researcher's record of analysis, thoughts, interpretations, questions, and directions of further data collection" (p. 110). Memoing helps the researcher organize ideas and guide conclusions and assertions.

Although most qualitative research asks the type of questions that are difficult if not impossible to subject to statistical analysis (Patton, 2002), the frequent use of concept maps in chemical education necessitates a brief discussion of quantifying a qualitative artifact. The following discussion of scoring concept maps is not meant to be a discussion of organizing qualitative data into tables, matrices, and charts (see Miles & Huberman, 1994), but a brief introduction to quantification of qualitative artifacts.

Novak and Gowin (1984) suggested scoring concept maps based on the organization of the map by awarding points for valid hierarchical levels and significant crosslinks. A "relational scoring method" was used by McClure, Sonak, and Suen (1999). An alternative scoring system proposed by Nicoll, Francisco, and Nakhleh (2001b) assesses the use, stability, and complexity of each link. Other scoring systems are described elsewhere (see Kinchin, 2000; Klein, Chung, Osmundson, Herl, & O'Neil, 2001; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). It should be noted, however, that researchers who decide to use a concept map as a data source or as analytic tool need to create an "expert" map before asking for a concept map from the participants (McClure, Sonak, & Suen, 1999; Nakhleh & Krajcik, 1994).

Validity Issues

Guba and Lincoln (1994) proposed two general sets of criteria for measuring the goodness of qualitative research: “trustworthiness” and “authenticity.” Denzin (1994) likened trustworthiness to the internal and external validity checks one would find in a statistical study. A variety of approaches can be taken to trustworthiness, including peer-review of codes, categories, and emergent themes by a colleague; member checking, a process by which participants review the analysis and assertions extracted from interviews in which they participated; and triangulation (the use of multiple sources of data). Guba and Lincoln (1994) equated the second criteria, authenticity, with the effect or influence the study had on the researcher, other instructors, or even the participants. Thomas and McRobbie (2001) and Venville (2004) provide examples of how data sources, data collection techniques, and data analysis can be applied to a theoretical perspective to probe the trustworthiness of a study.

A Detailed Example of a Constructivist Study

In their study of how students propose a mechanism for an organic reaction, Bhattacharyya & Bodner (2005) noted that:

> The ability to use the curved-arrow/electron-pushing formalism is one of the most vital skills in the organic chemist’s repertoire. Their introduction to this formalism occurs when they first encounter reaction mechanisms. As they gain experience, the arrow-pushing formalism eventually becomes the primary technique organic chemists use to do retrosynthetic analysis, to predict the chemoselectivity of a reaction, and to create novel methodologies. (p. 1402)

An example of the curved-arrow/arrow-pushing formalism taken from the work of Bhattacharyya & Bodner is shown in Figure 1.

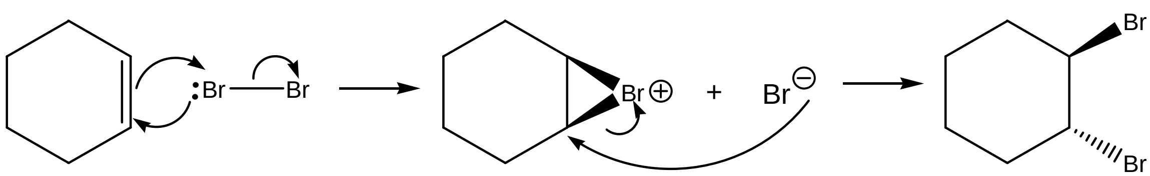

Figure 1: An example of the curved-arrow/arrow-pushing formalism

My motivation to study students’ understanding of the arrow-pushing formalism (APF) used by organic chemists (Ferguson, 2003) stems from my non-traditional route into synthetic organic chemistry research. Unlike many of my peers in graduate school, whose introduction to the APF was the result of extensive coursework, I learned the curved-arrow/arrow-pushing approach to organic mechanisms in an unstructured environment, while working in a synthetic organic research group.

My goal in designing my research was to investigate differences in the way undergraduates in a sophomore-level organic chemistry course made sense of the arrow-pushing formalism. I therefore formulated the following research questions:

- How do students make sense of the arrow-pushing formalism?
- What are the misconceptions?
- What are the processes that the students use to complete an arrow- pushing mechanism?

Constructivism was an appropriate research lens for investigating something as unstructured and unquantifiable as “understanding mechanisms.” Because the research questions focused on individual’s “sense-making,” either Kelly’s personal constructivism or von Glasersfeld’s radical constructivism were appropriate choices. I chose Kelly’s version of personal constructivism as the theoretical framework for this study.

The personal constructivism of Kelly asserts that “individuals construct knowledge for themselves through construing the repetition of events, and that knowledge is individual and adaptive rather than objective” (Geelan, 1997, p. 17). Individuals interact with the world in an iterative and reflective process, continually adjusting the fit between the world and the knowledge they construct. Bodner, Klobuchar, and Geelan (2001) summarized Kelly’s personal constructivism as follows:

> Kelly argues that we each create our own ways of seeing the world; the world does not create them for us. Each of us builds our own constructs, tries them on for size, and eventually revises them. (p.15)

Constructivism was consistent with the goal of my study: to understand how learners made sense of the arrow-pushing formalism. It also guided the choice of methodology to explore sense-making within the context of the arrow-pushing formalism.

My study was based on interviews with 22 undergraduate chemistry majors who volunteered to participate in problem-solving sessions in which they were asked to solve questions based on reaction mechanisms that were typical of a sophomore organic chemistry course (e.g., hydride reduction, Dieckmann condensation, Robinson annulation). During the semi-structured interviews, the participants constructed curved-arrow diagrams (artifacts) while they explained the flow of electrons using the think-aloud protocol. I audio-taped, video-taped, and then transcribed each interview.

Six students returned for a second, “member-checking” interview. The following vignette illustrates a typical member-checking interview (I = Interviewer; P = Participant):

> I: So in your opinion, right here, I put “no consideration of pKa.” Would there be a better way for me to phrase this? Or are you O.K. if I leave this? How would you like me to put it?

P: I am trying to think. Because I think that I consider but I don't consider as much pKa as just … I don't know how to term that either.

I: O.K., you do have some considerations, there but it seems like you more strongly, you rely more greatly on things like $\delta+/\delta-$, resonance, electronegativities. Those are things that you utilize more and pKa kind of toward the end of the list, low priority.

P: yeah … that sounds closer to,

I: more reasonable to you?

P: yeah.

The methodology used in this study was consistent with Lincoln & Guba's (2000) call for constructivist frameworks coupled with both hermeneutics and dialectics. The diagrams students created when they proposed mechanisms, the transcripts of the interviews, and the video-tapes of the interviews served as artifacts for the hermeneutic component of this methodology. These artifacts represented the "text" — both in the form of written diagrams and verbal responses — generated as the students answered the questions on mechanisms. This text became the data of this study, and ultimately the message of the students.

The initial and follow-up interviews were dialectic in their nature. Participants were asked:

- What is the first thing you do when solving a reaction mechanism problem?
- What do you do when you get stuck?
- What do you interpret this problem to mean?
- What are some clues that you look for when solving these problems?

I used the second interview to discuss the accuracy of my analysis and to check my understanding directly with the participants — a form of member checking. During the second interview, I reviewed my initial findings, categories, and understandings with the participants. At this meeting I asked the participants whether they agreed with my analysis. The participants inspected the data and any summations and interpretations that I derived. Member checking provided a method to appraise my observations and analysis, and to corroborate my ideas of the participants' understanding with the participants themselves. Through these conversations, the participants and I talked about each other's perspective and discussed possible answers to my research questions. Through this dialectical exchange, we came to a consensus.

Ultimately, I found that the undergraduates made sense of the arrow-pushing formalism in a complex and complicated manner. Because they lacked a firm grasp of the fundamental concepts they were expected to master, the undergraduate students viewed the arrow-pushing formalism as a meaningless exercise. From a pragmatic point of view, they understood what they were supposed to do; their artifacts showed a starting material being transformed into a product. They knew some of the fundamental rules of organic chemistry and applied them sparingly. They did not understand the concepts, theories, and rules that interacted during a reaction, however. When solving specific mechanism questions, they either did not remember the necessary concepts and rules, or they only remembered a part of this information. Concepts that they remember were often misapplied or confused it with a competing idea.

Conclusion

With its origins in the cognitive sciences, constructivism is unquestionably the dominant epistemology in science education. Since its incorporation into science education it has not only become a driving force in curriculum design but has been applied as a theoretical framework for research. Constructivism asks the question: How do individuals or groups understand reality? Researchers have employed a variety of methods such as interviews, think-aloud protocols, concept maps, and model-building to collecting data in research studies based on a constructivist framework. Constructivism is therefore a useful theoretical framework to consider for the researcher who is seeking to understand alternative conceptions, conceptual change over time, or the construction of knowledge.

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3

Symbolic Interactionism

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Biography

Dawn Del Carlo is an assistant professor of Chemistry at the University of Northern Iowa where she is a Jill of all trades, teaching chemistry, physical science and secondary science educational methods courses. She received her B.A. in Chemistry from Augustana College (in Illinois), and her M.S. in Inorganic Chemistry and Ph.D. in Chemistry Education both from Purdue University. Her doctoral dissertation examined the concept of academic dishonesty held by chemistry majors toward their classroom laboratory experiences. Immediately after graduation, she accepted a position as assistant professor in chemistry at Montclair State University in New Jersey where she extended her research to include high school students. After 3 years she returned to the Midwest, shifted the focus of her research slightly, and is currently looking at students' perceptions of their undergraduate research experiences with special emphasis on how pre-service and in-service teachers are affected by these experiences.

Introduction

Historically grounded in elements of George Herbert Mead's Chicago School of Sociology, the term "symbolic interactionism" was coined in 1937 by Herbert Blumer, a student of Mead's, as a pragmatist's theoretical and methodological approach to the study of social phenomena (Blumer, 2004). Symbolic interactionism is concerned with the construction of shared meanings (symbols) through social interaction and interpretation, and draws on the ideas and theories of William James, Charles Horton Cooley, John Dewey, and W. I. Thomas (Herman-Kinney & Verschaeve, 2003; Jacob, 1987; Meltzer, Petras, & Reynolds, 1975).

Goals of Symbolic Interactionistic Research

Patton (1990) argued that the goal of symbolic interactionism is to answer the basic question "What common set of symbols and understandings have emerged to give meaning to people's interactions?" In other words, how do people define their world and how does that definition shape their actions? (Charon, 1998). The focus of symbolic interactionism is “making society intelligible, rather than testing relationships between variables” (Jacob, 1987, p. 29). Consequently, the meanings people hold about their world are of central importance in symbolic interactionism and are governed by three premises (Blumer, 1969, 2004; Patton, 1990):

- Humans act toward the objects and people in their environments on the basis of the meanings these objects and people have for them.

- These meanings derive from the social interaction (communication, broadly understood) ... between and among individuals.

- Meanings are established and modified through an interpretive process undertaken by individuals in dealing with the things one encounters (Blumer, 1969, p. 2).

These statements imply that meaning is established only through social interaction. More explicitly, meanings are not held in individuals’ minds alone, but are social entities themselves and are consequently contextualized in the social environment. Therefore, any particular meaning is not determined by an individual’s experiences alone, but also by the social interactions or communications the individual has with his/her peers and the reflection of that individual on the interaction (Blumer, 1969; Gallant & Kleinman, 1983). In essence, symbolic interactionism:

> … describes the intricate interrelationships between the individual and society: Society makes the individual through creation of the self, mind, symbols, generalized other, perspectives, and symbolic role taking. Conversely, it is the human individual who makes human society through active interpretation, self-direction, role taking, aligning his or her own acts with others, and communicating. (Charon, 1998, p. 232)

Results arising from the use of a symbolic interactionistic approach to research are centered around constructing a basic understanding of how people act based on the definitions and meanings they hold of the world around them.

Assumptions of Symbolic Interactionism

Two main assumptions of symbolic interactionism involve its treatment of reality and the nature of interaction and behavior. Rooted in the philosophies of pragmatism and interpretivism, symbolic interactionism defines reality as an evolving entity that depends on social interaction. Reality is socially constructed and is based on what we find to be “useful” (Charon, 1998):

> We converse with ourselves, we make decisions along a continuous stream of action. Truth for us always changes, our symbols do, rules change, our use for our environment changes. What we are today is different from what we were

> yesterday … People are not thought to be brainwashed and conditioned so much as actively involved in testing and reassessing their truths. (p. 32)

As an over-simplified example, children might use large cardboard boxes strung together to create a “fort” in which to play after their parents unpacked the boxes that were originally used when the family moved into a new house or apartment. The same object, or symbol, has a different meaning (or reality) for the person, depending on his or her interaction with the object, and consequently, different behaviors involving the symbol — here, the cardboard box — are observed. The reality, or reason for existence of this box, is different for the parents than for the children who each interact with this object differently. The reality of the box is not innate to the box itself but exists in how the box is used by a particular person or group of people.

Symbolic interactionism is heavily influenced by elements of behaviorism. Mead (1934) argued:

> Social psychology is behavioristic in the sense of starting off with an observable activity … to be studied and analyzed scientifically. But it is not behavioristic in the sense of ignoring the inner experience of the individual … On the contrary it is particularly concerned with the rise of such experience within the process as a whole. (pp. 7-8)

Unlike “traditional” behaviorism, which is based on the premise that stimulus-response behavior is the result of previous conditioning or instinct, symbolic interactionists believe interpreted meaning begets social behavior, which, in turn, further constructs meaning through the social interaction. It is this process of meaning construction and resultant behavior that symbolic interactionists seek to understand (Jacob, 1987).

These elements of behaviorism are what separate symbolic interactionism from frameworks such as social constructivism (Chapter 2) and situated cognition (Chapter 11) which are more focused on the cognitive aspects of social construction of knowledge or reality (Lave & Wenger, 1991; Schwandt, 1994). Symbolic interactionism, on the other hand, is focused on observable behavior, the cognitive meaning behind the behavior, and the interplay between the two.

Methods of Symbolic Interactionism

Symbolic interactionism seeks to understand the underlying meanings of observable behavior and interactions. Therefore, qualitative methods of data collection — including participant observation, interviews, and life histories — are the most useful methodologies, although, on occasion, mixed-methods and social experiments such as the laboratory experiment and the quasi-experiment, are also used (Herman-Kinney & Verschaeve, 2003; Ulmer & Wilson, 2003). It should be noted, however, that Blumer’s original conception of symbolic interactionism adamantly opposed the use of quantitative measures, which were commonplace in sociology and psychology at the time (Blumer, 1969).

Participation observation, in which the research actively participates in and is, in part, socialized into the group under study, plays a central role in symbolic interactionist methods (Herman-Kinney & Verschaeve, 2003; Jacob, 1987). As Blumer noted:

> The empirical social world consists of ongoing group life and one has to get close to this life to know what is going on in it. If one is going to respect the social world, one's problems, guiding conception, data, schemes or relationships, and ideas of interpretation have to be faithful to that empirical world. (1969, p 38)

Also referred to as "sympathetic introspection" (Meltzer et al., 1975), or *verstehen* — meaning "understanding on a personal level the motives and beliefs behind people's actions" (Taylor & Bogdan, 1998, p. 4) — participant observation is clearly ethnographic in nature (see Chapter 10), and is used to generate an "understanding of the ways of life of others" (Schwandt, 2001, p. 186). The challenge of participant observation is that the researcher must become part of the studied group enough to understand it as a member of that group, but yet, also be able to step back and describe and analyze the observations such that they are understandable to outsiders. Detailed and reflective field notes are especially helpful in this regard and should be diligently taken for all observations. It is often easiest to take shorthand notes during the observation period and then transcribe the notes shortly thereafter, filling in the detail while it is still fresh in the researcher's mind. Never assume that something is significant enough to be remembered at a later time (Patton, 1990).

Depending on the extent to which the researcher participates within the population being observed, the meaning constructed from social interaction may or may not be readily apparent. Other techniques such as interviews (open-ended, structured or semi-structured in nature), or collected artifacts such as life histories, public documents, and journals/diaries are often used to supplement observation notes. Through interviews and the completion of artifacts, study participants reflect on their behavior and are given the opportunity to explain the meaning their behavior or artifact holds for them (Herman-Kinney & Verschaeve, 2003). For example, a researcher may ask participants to keep a journal throughout a particular experience which describes their thoughts, feelings, actions, and decisions. These journal entries will inevitably illustrate the meaning these experiences had for the participants. Moreover, focus group interviews can be used to ascertain socially constructed meaning in a more researcher-controlled atmosphere than the naturalistic or original observed setting. This allows the researcher to probe participants for meaning without losing the social aspect of the construction of meaning (Herman-Kinney & Verschaeve, 2003; Morgan, 1988).

Data Analysis

Blumer considered himself an empiricist and believed that a researcher's conclusions should be a direct result of the observed social world (Blumer, 1969). The goal for symbolic interactionists is therefore "to develop theory that accounts for behavior rather than to develop descriptions of behavior with the goal of verifying theory" (Jacob, 1987, p. 31). Consequently, researchers use a grounded theory approach — utilizing their collected data as the starting point of analysis — and do not approach their study with a predetermined hypothesis in mind (Charmaz, 2000; Strauss & Corbin, 1990; Taylor & Bogdan, 1998). Instead, the research design and focus must remain somewhat flexible, with preliminary data informing the direction of future data collection through a "sensitizing framework" (Jacob, 1987; Patton, 1990). Blumer (1969) refers to this as the exploration phase of analysis:

> It is the way by which a research scholar can form a close and comprehensive acquaintance with a sphere of social life that is unfamiliar and hence unknown to him. On the other hand, it is the means of developing and sharpening his inquiry so that his problem, his directions of inquiry, data, analytical relations, and interpretations arise out of and remain grounded in, the empirical life under study. Exploration is by definition a flexible procedure in which the scholar shifts from one to another line of inquiry, adopts new points of observation as his study progresses, moves in new directions previously unthought-of, and changes his recognition of what are relevant data as he acquires more information and better understanding. (p 40)

As data are collected, they are reviewed almost immediately, so that data collection and data analysis occur concurrently throughout the study. The researcher examines and re-examines the data (which may include not only texts but objects, pictures and diagrams depending on the nature of the study), looking for themes of action and possible meanings to emerge. These themes then shape how the researcher approaches future data collection with regards to the types of behaviors, conversations, and interactions that are observed and noted (Patton, 1990). It should be noted that this method is not used to pin-point specifically *what* to look for or questions to ask, but only to suggest a *direction* in which to look (Jacob, 1987).

Symbolic interaction is unique in that analysis is viewed through a lens where the group or individual being examined is seen "as a moving process in which the participants are defining and interpreting each other's acts" (Blumer, 1969, p. 53). When an individual's act is understood by the researcher as it is understood by the individual himself, data collection and analysis is complete (Blumer, 1969).

Criticisms of Symbolic Interactionism

The focus of symbolic interactionism is on meaning that is *socially* constructed; therefore, little attention is paid to psychological phenomena which are specific to the individual, such as human emotion and the unconscious (Meltzer et al., 1975; Stryker, 1980). In fact, Mead specifically describes both the "I" and "me" as being socially constructed identities. The difference between the two originates from the stage of reflection of the individual (Mead, 1934):

> I talk to myself, and I remember what I said and perhaps the emotional content that went with it. The "I" of this moment is present in the "me" of the next moment … The "I" is the response of the organism to the attitudes of the others; the "me"

> is the organized set of attitudes of others which one himself assumes … it is the presence of those organized sets of attitudes that constitutes that "me" to which he as an "I" is responding. (pp. 174-175)

Mead describes the "I" as the persona interacting socially; the persona that others see. The "me," on the other hand, is the current persona or self which reflects on the interactions of the "I," and changes existing attitudes and beliefs accordingly. Consequently, the "me" of the present is governed by the past social interactions of the "I", which makes both entities socially constructed.

Cooley (1998) described the idea of an "I" as a "social self," further embedding identity and constructed meaning within a social context. This ignores all reference to the unconscious aspects of human behavior important in the psychological theories of Freud and Jung which is the premise of Brittan's critique of symbolic interactionism (Brittan, 1973). In essence, by embedding meaning within a social context, symbolic interactionism treats human emotions, desires, motives and aspirations — which Freud describes as the "Id" — as social entities, ignoring the individualistic traits inherent in each. Consequently, the individual is lost within the socially determined norms.

Since meaning and reality are dependent on the particulars of social interaction, the concept of reality is not an objective one and existing realities, such as social structure and class, are largely ignored (Meltzer et al., 1975; Stryker, 1980). This results from the pragmatic influence on symbolic interactionism, and, while an objective reality is acknowledged, that objective reality is not examined under this framework (Charon, 1998; Johnson & Picou, 1985):

> Instead, we *define* the situation "as it exists" out there, and that definition is highly influenced by our social life…we learn in social interaction what to see in objective reality and how to define what we see. (Charon, 1998, pp. 42-43)

As a result, the specific situation under study also becomes an element of analysis, and since two situations are never identical, symbolic interactionism does not generate testable hypotheses or generalizable results (Denzin, 1969; Meltzer, Petras, & Reynolds, 1975). This critique is carried over to the specific research methodologies, namely participant observation, where the researcher is part of the situation, and may influence the interaction, such that results can sometimes reflect researcher bias rather than observed behavior (Patton, 1990; Stryker, 1980). Consequently, it can be argued that whatever theories emerge will necessarily be different when the study is performed by another researcher. In fact Meltzer et al. (1975) states that symbolic interaction "often results in an over-emphasis on the situation and an obsessive concern with the transient, episodic, and fleeting" (p.85).

Since symbolic interactionism relies on the analysis of the interaction between *individuals*, it is not appropriate for understanding large-scale social organizations — such as governments, school districts or large corporations — and their effect on an individual's behavior or on other organizations. Instead, this framework is best suited for developing an understanding of the specific social structures themselves and the individuals that compose it (Stryker, 1980).

Potential Educational Benefits of Symbolic Interactionistic Research

Unlike much of the educational research one traditionally thinks of with regard to learning, cognition, and individual student academic outcomes, educational studies framed by symbolic interactionism focus on the social interactions within schooling that strongly influence and shape learning (Kinney, Rosier, & Harger, 2003). Generally speaking, it can be said that interactionist studies contribute to the growing amount of information pertaining to classroom and school climate or culture by examining student-student, student-teacher, teacher-teacher, or teacher-parent interactions. Ultimately this culture affects student learning and performance, and in order to be effective educators it is prudent to have a basic understanding of the culture that exists in their classrooms (Fraser, 1994; Kinney et al., 2003). By subscribing to the tenets of symbolic interactionism, educators understand that “whatever was gained [in the classroom] will be changed considerably as [students] interact *now* with new people” (Charon, 1998, p. 230).

As will be seen in the following section, studies which examine the experiences specific to pre-service and student teachers have implications for teacher education programs. Understanding how pre-service and even new in-service teachers develop their beliefs and practices based on their courses and experiences in the classroom can shape what activities and experiences teacher education programs expose them to before getting out in the field (Abell & Roth, 1992, 1994; McGinnis & Pearsall, 1998; Southerland & Gess-Newsome, 1999).

An additional area of growing interest is in the “culture” of science and scientific research that can be traced back to the 70’s (Latour & Woolgar, 1979). While not explicitly interactionist in nature, Latour’s work sought to understand the culture of science and scientific knowledge. This understanding came about by observing the interactions of practicing research scientists in a laboratory setting. Understanding the difference in culture between the classroom laboratory in which educators train future practitioners and the culture of practitioners has great implications for science education (Seymour, Hunter, Laursen, & Deantoni, 2004).

Published Examples of Symbolic Interaction Studies in Science Education

While published studies using symbolic interactionism in mathematics education are plentiful (Cobb, Stephan, McClain, & Gravemeijer, 2001; Radford, 2003; Trouche, 2003; Yackel, Cobb, & Wood, 1998) — including several books on the subject (Cobb & Bauersfeld, 1995; Wood, Wood, Nelson, & Warfield, 2001) — studies in science education are less so. A comprehensive literature search in this case was difficult due to the fact that science education studies using symbolic interactionism can be published in social science, educational psychology, or cultural study journals as well as traditional science education journals (see Table 1). I searched eight common science/chemistry education journals,[1] and additionally performed keyword searches within the journal *Symbolic Interaction* and several databases including ERIC, PsyINFO, and Google Scholar to generate a varied sample of science education studies conducted using this framework. Rather than trying to "fit" research studies into a certain framework where none was reported, references included in this review explicitly stated that symbolic interactionism was used as a framework. Studies in science education that used this framework generally focused on one of three topics: 1) pre-service teacher preparation, 2) in-service teacher practices, and 3) student perspectives and experiences in science.

Table 1: Summary of Literature using SI Framework

Authors	**Research Questions or Purpose of Study**
Abell & Roth, 1992	What beliefs about elementary school science education does a science enthusiast student teacher possess? How does her teaching reflect and influence these beliefs? How do the constraints she perceives to her teaching interact with these practices and beliefs?
Abell & Roth, 1994	How does a student teacher, who is enthusiastic about teaching science in the elementary school, cope with conflicts between her beliefs about science teaching and learning and the constraints she perceives to her teaching?
Del Carlo & Bodner, 2004	What are chemistry students' perceptions of academic dishonesty in a laboratory based class? and What distinction, if any, do these students make between academic dishonesty in the classroom laboratory and scientific misconduct that may occur in a research laboratory?
Dillon, O'Brien, Moje, & Stewart, 1994	How were literacy events shaped by the teachers' philosophies about teaching science content and teaching students? How was literacy (reading, writing, and oral language) structured by the teachers and manifested in science lessons?
Gohn, 2004	How do leadership teams develop a team culture within the milieu of school and community and how do these teams function in building teacher leadership and extending science education reform, addresses complex social phenomena?

[1]Searched journals include: *Chemistry Education: Research and Practice*, *International Journal of Science Education*, *Journal of Chemistry Education*, *Journal of Research in Science Teaching*, *Research in Science Education*, *Science Education*, *Science and Education*, and *The Chemical Educator*.

Helms, 1998	What is the nature of secondary science teachers' sense of personal and professional identity with respect to their subject matter?
Hyde & Gess-Newsome, 1999	What characterized the experience of the women who stayed in science and graduated successfully? What type of interactions and events impacted their decision to persist? What types of relationships were meaningful to their experiences, and did those associations help them to persist in their academic pursuits? What was the nature of their context? Did the university's special programs for female MES students make a difference in female persistence?
McGinnis & Pearsall, 1998	The purpose was to gain insight into the effect of the gender difference between a male professor and his female teacher candidates on the outcomes of an elementary science methods course.
McGinnis et al., 2004	As they proceed through their induction years, how do beginning specialist teachers of mathematics and science who graduate from an inquiry-based, standards-guided innovative undergraduate teacher preparation: (a) enact their roles as teachers? and (b) think about what they do when teaching science and mathematics to upper elementary/middle-level students? And secondly, what affordances/constraints impact the introduction of new practices (reform-based) by beginning specialist teachers of mathematics and science who graduate from inquiry based, standards-guided, innovative undergraduate teacher preparation?
Simmons et al., 1999	What are the perceptions, beliefs, and classroom performances of beginning secondary science and mathematics teachers as related to their beliefs and philosophies of teaching and their content pedagogical skills?
Smardon, 2004	This study seeks to elaborate the importance of group membership and group identity in constructing a science culture in the classroom.
Southerland & Gess-Newsome, 1999	Purpose is to detail pre-service teachers' understandings of teaching, learning, and knowledge and describe how these pedagogical understandings influenced their approach to inclusive science teaching.

Van Sickle & Spector, 1996	What is happening in science classrooms with teachers who are perceived to be caring?
Zeidler, Walker, Ackett, & Simmons, 2002	In what ways are students views of the nature of science reflected in their reactions to socio-scientific issues when confronted with information that challenges their initial beliefs?

Studies in pre-service teacher education that used symbolic interactionism as their theoretical framework examined either the student teaching experience (Abell & Roth, 1992; Abell & Roth, 1994) or events within the methods course (McGinnis & Pearsall, 1998; Southerland & Gess-Newsome, 1999). Abell and Roth reported the results of a study of the beliefs a student teacher held pertaining to elementary science teaching, how those beliefs shaped her actions (1992), and how she coped with perceived limitations in her science teaching (1994). Another study (Southerland & Gess-Newsome, 1999) examined pre-service elementary teachers' epistemological and pedagogical beliefs and sought to understand how these beliefs influenced a pre-service teacher's planned approach to teaching diverse populations of students. All three studies focused on future teachers' understandings and knowledge and how those manifested themselves as behaviors in the classroom.

The fourth study in this category involved a methods course (McGinnis & Pearsall, 1998). This study of pre-service elementary teachers was more exploratory in nature and examined how a male instructor for a predominantly female student population affected the outcomes of the course. The report is told from two different perspectives: that of the male instructor and that of the female co-researcher in an effort to illustrate the difference in the gender-imposed lenses.

Most of the published accounts of in-service teachers that utilize a symbolic interactionist framework focus, not surprisingly, on the continuity (or discontinuity) between teachers' understandings of science content, pedagogy, and pedagogical content and their actual classroom practices (Dillon et al., 1994; Helms, 1998; McGinnis, Parker, & Graeber, 2004; Simmons et al., 1999; Van Sickle & Spector, 1996). However, each report takes a slightly different slant. Simmons et al. (1999), for example, limited their study to teachers in their first three years of teaching and specifically examined how teacher beliefs, practices, and their incongruencies evolved over the three years. Similarly, McGinnis et al. (2004) examined teachers in their first two years of practice with regards to their understandings and implementation of inquiry-based teaching methodologies in elementary/middle-level science and mathematics classrooms.

Other studies were less concerned with what happens in the beginning years of teaching and instead focused on specific characteristics of teaching. Van Sickle & Spector (1996), for example, studied the behaviors and classroom culture established by middle and secondary science teachers who were perceived by students and colleagues as being "caring." Helms (1998) related middle-level and secondary science teachers perceived level of content knowledge to their sense of "professional" self. This sense of self dictates teachers' teaching behaviors in their classrooms. In the last of the fours studies in this category, Dillon et. al. (1994) looked at how science teachers with additional experience in — and consequently established philosophies about — literacy, incorporate teaching strategies in science to accommodate those philosophies.

Unlike the studies of in-service teachers previously listed, which focus directly on specific classroom practices, Gohn (2004) looked at how teachers come together to implement curricular reform. Instead of focusing on the behaviors of teachers within their classrooms, this study examined how teachers interact with one another in the groups established to create and disseminate professional development plans for district-wide curricular reform (Gohn, 2004).

Other studies have examined the students' perspective (Del Carlo & Bodner, 2004; Hyde & Gess-Newsome, 1999; Smardon, 2004; Zeidler et al., 2002). All of these report on some aspect of "culture" from the student's point of view including the culture of the classroom (Del Carlo & Bodner, 2004; Smardon, 2004), science education school-wide (Hyde & Gess-Newsome, 1999), or science in general (Del Carlo & Bodner, 2004; Zeidler et al., 2002). Smardon (2004) used symbolic interactionism as a starting point for the development of a new socio-cultural model of how urban students negotiate cultural codes between the "street" and a chemistry classroom. Hyde & Gess-Newsome (1999) examined the experiences and culture established by female science, math, and engineering majors on their college campus which encouraged them to persist in their majors. Zeidler et.al. (2002) focused on how students perceived the established culture of science to deal with socio-scientific dilemmas such as animal testing.

The study by Del Carlo & Bodner (2004) fits into two of the above categories since it deals with students' perceptions of academic dishonesty within chemistry. Specifically, it addresses the perceived culture within a chemistry classroom laboratory and compares that to the perceived culture of scientific research in an effort to understand student behaviors and decisions in both contexts. This study is described in detail in the following section.

A Detailed Example of a Symbolic Interactionistic Study

As a student interested in chemistry from my first experience with it in high school, I noticed over the years that my attitude toward the collection and treatment of data has evolved. Early in my education, I clearly made the distinction between data collected in a classroom laboratory for a grade and the data I collected as part of a research project. The former had a clear "right" answer, which data could be altered to reflect, whereas the latter illustrated whatever phenomenon was under study and consequently could not be fudged. While the current literature is filled with studies on cheating, plagiarism, and various other forms of academic dishonesty, most of this literature focuses on tests, papers and homework assignments (see, for example: Derting, 1997; Lord & Chido, 1995; Maramark & Barth Maline, 1993; McCabe, 1997; Singhal, 1982). Relatively few studies have explored students' attitudes toward dishonest behavior in the unique atmosphere of a science teaching laboratory (Mazzaro, Del Carlo, & Page, in press; Rigano & Ritchie, 1995; Ritchie & Rigano, 1996; Syer & Shore, 2001).

Symbolic interactionism was the best framework for this study because it not only examined the actual behaviors of students in a classroom laboratory but also uncovered the meanings these behaviors hold for students. My focus was on the ethics or ethical philosophies, “objects” in symbolic interactionist terms that students possess and develop through their interactions with other students, research advisors, professors, or teaching assistants in the laboratory setting. How students act in the environment is determined by the meanings that these symbols, or ethical philosophies, have for them. These actions and interactions within the laboratory environment play an important part in the evolution of meanings for the individuals involved in the interaction. The laboratory is itself a social environment in which these contextualized actions take place and, therefore, possesses some social meaning for those individuals participating in that environment.

The use of symbolic interactionism as a theoretical framework for this research implied that students’ actions could be used to understand what academic dishonesty means for them and how that meaning evolved through their interactions in a laboratory setting. More specifically, this study aimed at answering the following guiding research questions:

- What meaning does academic dishonesty have for students in a classroom laboratory?

- What changes in meaning occur when the lab environment is research oriented instead of academic?

- How do these meanings evolve with continued interactions throughout the students’ academic careers?

Over the course of one semester, I observed and took detailed field notes in four different college level chemistry lab classes for chemistry majors — 100-level general chemistry, 200-level inorganic, 300-level analytical, and 400-level instrumental analysis. I was not involved as an instructor in any of these classes. I noted behaviors, actions, interactions, and events students participated in during the course of their lab period. Having a background in chemistry I functioned as a participant-observer, moving about the laboratory, interacting with the students, participating in their conversations, as well as answering questions for the students about myself, the study, or topics in chemistry.

After students were comfortable with my presence in the lab, I solicited for volunteers to participate in either an individual or focus group interview. Eight individual and 9 group interviews were conducted involving close to 100 students. Interviews were used to ascertain the meanings held by the students of events that took place in the classroom laboratory. Individual interviews allowed me as a researcher to ask probing questions regarding meaning, while the focus group interviews, in addition to allowing for meaning exploration, allowed the social aspect of interaction to remain present despite the fact that the interview did not take place in the laboratory setting. It was also during the interviews that questions about students' research experiences were explored. Even though research laboratories were not part of the observations, the interviews allowed me to examine how the context of environment affected students' meanings.

As data collection progressed, notes and interviews were transcribed into electronic form for further analysis and helped shape future observations and interview questions. After reading and re-reading transcripts, common themes regarding student attitudes, behaviors and perceptions of science emerged. These themes became the meanings students held behind the observed classroom laboratory behaviors and led to two main assertions (Del Carlo & Bodner, 2004):

- Students believe that the classroom lab is fundamentally different from a research or industrial lab.

- This difference is so significant that it carries over into students' perceptions of dishonesty in these two environments.

Students felt that the purpose or meaning behind the classroom laboratory was to ascertain some predetermined "right" answer. The classroom laboratory may also be used to illustrate a certain concept or technique, but was primarily seen as a hurdle to overcome especially given the restrictive time schedule of a 3-hour lab period and equipment or technical difficulties that were not perceived to be the students' "fault." While actual data fudging was rare, data "sharing" between lab groups was common and, in one case, after making the students perform the laboratory exercise, the professor noted that it never yielded data "good enough" for analysis and provided the class with a separate set to use in their lab reports.

The students in this study, at all levels from general chemistry through the capstone course in analytical chemistry, believed that the industrial- or research-laboratory setting fostered a fundamentally different environment when compared with the classroom laboratory. While there still might be a "right" answer it was certainly not predetermined; and, consequently, data fudging, copying, or any kind of manipulation held much greater ramifications in the long run.

Interestingly, students began to hold a similar meaning about the "real" lab within their classroom laboratory when they performed one of two independent projects assigned for the class.[2] In both cases, the outcome of the project was unknown and students expressed a sense of ownership over their project. Consequently, these assignments held a different meaning for the students and their behavior toward them was different than the other exercises assigned. Students failed to see the advantage in copying or

[2] The 200-level inorganic class assigned a 20-unknown qualitative analysis project and the 400-level instrumental analysis class required students to devise their own unique question and method of analysis using techniques and instruments studied over the course of the semester.

fudging their data in their projects. This implies that by using project-oriented or inquiry-based experiments, the meaning of the chemistry classroom laboratory and subsequently, academic dishonesty can be changed, and dishonest behavior lessened.

Since students as early as their freshman year believed there was a difference between the classroom and a “real” laboratory setting, these results also provide support for encouraging students to participate in research earlier, rather than later, in their academic careers. This is a movement in science education gaining in popularity and support as more research is done on the benefits of participating in undergraduate research (Seymour et al., 2004).

Conclusion

This chapter outlined the principles of symbolic interactionism including its assumptions about human behavior, interaction, construction of “self,” and perception of reality. Each principle is intricately connected to the other and are what give symbolic interactionism its strength as a framework.

The main focus in symbolic interactionism is on understanding the process of the construction of meaning (or reality) through examination of behavior. Consequently, it is most often used as a framework in chemistry/science educational research when a broad understanding of “culture” is needed. This culture represents the “reality” which has been constructed by the members of that culture. How the members act is a reflection of their understanding of reality and also contributes to further development of that culture.

As illustrated in the section on published examples, this culture can be understood through the eyes of one member (as in a case study) or several as in studies that examined the meanings held by several members of the population. However, because it relies on the direct interaction among its participants, symbolic interactionism is probably not an appropriate framework to study complex or multi-level social systems. Most universities, for example, function on many levels; student, untenured professor, tenured professor, department head, dean, provost, president. With the exception of exceedingly small institutions, it is rare for a president to have continued interactions with the students on campus from which these students define their world to shape their behavior in a classroom. Symbolic interactionism would not be appropriate for such a study.

Conclusions made from research using symbolic interactionism do not offer simple implications. While it may help us to understand a situation, it does not immediately offer solutions to “fixing” perceived problems. In the case of the students who fudge their classroom laboratory data, this culture of acceptance stems from deeply ingrained attitudes and perceptions about how the world works — both inside and outside of the classroom. Eliciting a change in this behavior, implies changing an entire established culture and the meanings behind the undesirable behavior. Unlike behaviorism and the classic example of Pavlov's dog, changing the meaning behind a behavior goes well beyond simply rewarding the desired behavior.

Symbolic interactionism also would not be an appropriate framework to study learning or cognition alone. As stated in its name, *interaction* is a crucial part of this framework. Involved in the analysis must be observations of behavior and interaction as well as an examination of the cognitive processes involved in that interaction. For example, determining what students learn in a typical general chemistry class would not be framed by symbolic interactionism if a simple pre-/post-test experimental design were used. However, examination of what the students experience, how they behave and interact with one another and the professor before, during and after completion of the course, and using that information to complement the test scores, would be better suited to the symbolic interactionistic framework.

Finally, since symbolic interactionism focuses on a constructed reality, rather than an objective one, the conclusions reached, are not generalizable across populations (or even individuals). While we might be able to say that there is one definition of the world that exists among chemistry majors at State U., the definition among chemistry majors at Small College, may be very different. For example, the results of the study presented above originated at a large research-based institution where most classroom laboratories utilized cookbook-style experiments and are taught by graduate teaching assistants. The meanings of academic dishonesty are based on these (and other) social structures specific to the institution and the people within it. It is not difficult to imagine that the laboratory culture and the culture of academic dishonesty would be significantly different at a small college. Even if several other variables are the same (i.e. cookbook labs and student teaching assistants), the interactions between members of each population are different, making the meanings for the first population not applicable to the second. Symbolic interactionism, an exploratory framework, is used to gain a better understanding of the population at hand, which in turn can give us only a preliminary understanding of other populations we may be interested in studying.

Schools of Thought: Chicago, Iowa, Indiana and Beyond

In response to the various criticisms of symbolic interactionism, several different "schools of thought" arose from Mead's original tenets of sociology. Blumer, who has predominantly been the focus of this chapter, represents Mead's Chicago School of thought; however Manford Kuhn and Carl Couch are credited for developing the "Old" and "New" Iowa Schools respectively, and Sheldon Stryker is known as the creator of the Indiana School (Herman-Kinney & Verschaeve, 2003). While a complete description of each school is beyond the scope of this chapter, a brief discussion highlighting the differences, versatility, and evolutionary nature of this framework is warranted.

Unlike Blumer, who took an interpretivistic approach to symbolic interactionism, Kuhn was more positivistic in his method. Because positivism emphasizes a static and empirical version of reality, Kuhn's focus was less on the relativistic and changing nature of reality, and instead emphasized the empirical testing of hypotheses and making general statements regarding human behavior by quantifying "the self" (Herman-Kinney & Verschaeve, 2003; Meltzer et al., 1975). Consequently, the specific methodological approaches vary greatly between the two schools with Kuhn and the Iowa school relying mainly on quantitative measures, or semi-qualitative techniques such as scripted interviews (Meltzer et al., 1975). According to Herman-Kinney and Verschaeve (2003), "Kuhn's mission was to find social life that was controllable, predictable, stable and ordered" (p. 223).

The "New" Iowa school is attributed to the efforts of Couch who carried on Kuhn's procedures after his death in 1963. Additionally, Couch expanded his procedures to outside the social experimental laboratory with the use of audiovisual technology and shifted his focus toward studying the finer details of the processes of interaction (Katovich, Miller, & Stewart, 2002). In comparison, the Chicago school historically focused on the symbolic meaning of interaction.

Sheldon Stryker and the Indiana School also sought out regular patterns of social interaction, but expanded their work on complex social systems into models of the mind in artificial intelligence (Herman-Kinney & Verschaeve, 2003). Due to the complicated nature of the systems under study, the Indiana School also tends toward quantitative measures, and has led to the development of several mathematical models of social systems. The Indiana school is the most recent twist on symbolic interactionism, and illustrates the fact that it is a constantly evolving framework.

The last two approaches are commonly referred to as "branches" of symbolic interactionism. The first, Garfinkel's Ethnomethodology, is often associated with conversation analysis, and is described in detail in Chapter 10. The second, is Erving Goffman's Dramaturgical Genre which focuses on the dramatic nature of interaction. (Charon, 1998; Herman-Kinney & Verschaeve, 2003; Meltzer et al., 1975). For Goffman, people function as actors in their reality and "put on a 'show'" in an effort to control the impressions they give off to others (Meltzer et al., 1975, p. 68). The meanings which are constructed by an individual are based on these impressions and consequently shape the actions of the other "actors." It is through these interactions that "social actors also attempt to manage others' impressions of the groups establishments, and organizations they represent" and control their social situations (Charon, 1998, p 194). These examples further illustrate the dynamic nature of symbolic interactionism and its many applications.

With the exception of ethnomethodology, which is considered a separate theoretical framework, it might seem at first that it would be difficult to make distinctions in the research literature as to which "school of thought" of symbolic interaction is being used. Once one recognizes that the methodologies are the most distinguishing characteristics of the different schools — Iowa and Indiana, quantitative and Chicago, qualitative — differentiation becomes a bit easier. I did not find studies in science education using the dramaturgical genre, but as long as the "sage on the stage" model of teaching is used, it is easy to see the potential research directions that can use this particular branch of symbolic interactionism.

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4

Models and Modeling: A Theory of Learning

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Biography

Mike Briggs is an assistant professor of Chemistry at Indiana University of Pennsylvania. He traveled a circuitous path to this position. As a teenager, he pondered the question of why people think and act the way they do. As a platoon leader in Viet Nam, he carefully observed how soldiers handled fear on the battlefield. He considered how they rationalize the risk of death and acted according to their views. Later Mike took up flying and became a certified flight instructor. Again, he observed how flight students handle their fear of heights, the risk of crashing, and the development of flight skills. He found that students were developing mental models of aircraft performance that were at variance with accepted physical laws. These naïve mental models affected the developing flight skills and determined student success in the course. In industry, as manager of technical departments in the rubber industry he observed that many machine operators had developed great skill at producing quality products, without any technical training, by constructing mental models of the structure and processes of their machines. Often the mental models were flawed … but worked! These observations lead to a growing desire to understand how people, students in particular, constructed their knowledge. At the end of the millennium, Mike went to Purdue University to study with George Bodner and found the answer to the question he pondered as a teenager.

Introduction

The Models and Modeling paradigm, as developed by Lesh, Hoover, Hole, Kelly, and Post (2000) and Case, Okamoto, Stephanson, and Bleiker (1996), is a powerful research tool at several levels. As a theoretical framework, it opens a window on the mental activities of participants. As a methodological framework, it provides a method — thought-revealing activities — of inducing people to verbalize what they are thinking about while working on a task or problem. As an analytical framework, it provides a basis for building a deeper understanding of mental activities. In this chapter, I will focus on the characteristics of Models and Modeling that allow it to be used as a theoretical perspective for research in chemistry and science education.

The focus of the Models and Modeling theoretical framework is the construction of knowledge. It is therefore useful in answering questions of the kind, “What are the mental structures and processes students must possess for learning chemistry?” Models and Modeling can be viewed as building on the constructivist theory described in Chapter 2. Because the Models and Modeling framework tries to provide an understanding of the mechanism by which knowledge construction occurs, Lesh and Doerr (2003) based the title of their most recent book on this framework: *Beyond Constructivism.*

The specific implementation of the Models and Modeling perspective discussed in this chapter was developed by Lesh et al. (2000) over a period of 20 years. In an independent research program, Case et al. (1996) developed a similar mental model of learning by studying young children. The Models and Modeling theoretical perspective also grew out of the principles of Action Research (Doerr & Tinto, 2000) as a method to “… simultaneously study and generate knowledge about the very practice that it seeks to change” (p. 408). Moschkovich and Brenner (2000) viewed the paradigm as a coherent research activity in which “… theory and methods are intricately related, mutually constructive, and informing of each other” (p. 459). In order to obtain data on the actual thought processes that learners used to traverse a solution path through a problem, the Models and Modeling paradigm uses thought-revealing or model-eliciting activities (Lesh et al., 2000), which are described below.

Antecedents of the Models and Modeling Paradigm

Before the reader can fully understand the Models and Modeling framework, it is important to recognize how the term *model* has been used in science education in recent years. Bodner, Gardner and Briggs (2005) summarized some of the attempts that have been made to describe the characteristics of a model within the context of science education as follows:

- A model is a representation of an idea, object, event, process, or system, which concentrates attention on certain aspects of the system — thus facilitating scientific inquiry.

- Mental models represent significant aspects of our physical and social world, and we manipulate elements of these models when we think, plan, and try to explain events in that world.

- A model relates to a target system or phenomenon with which we have a common experience or set of experiences.

- Models are mental entities that people construct with which they reason; all of our knowledge of the world therefore depends on our ability to construct models of it.

- Scientific models are conceptual systems mapped onto a specific pattern in the structure/behavior of a physical system within certain limits of reliability. (p.68)

The origins of the concept of mental models trace back at least 2500 years, to Plato's allegory of prisoners in a cave who obtain all of their information about the world from shadows cast on the wall of the cave (Plato, 1952). In this allegory, Plato alludes to the construction of mental models as representations of real world objects. The prisoners' activities are similar to our own activities when we muse about chairs we saw the day before. We do not carry chairs around in our heads but rather mental models of chairs, which we use in our thinking about chairs.

A modern view of the concept of mental models was proposed by Johnson-Laird:

> We seem to perceive the world directly, not a representation of it. Yet this phenomenology is illusory: what we perceive depends on both what is in the world and what is in our heads–on what evolution has "wired" into our nervous systems and what we know as a result of experience. The limits of our models are the limits of our world. (Johnson–Laird, 1989, p. 471)

The Constituents of the Models and Modeling Framework

One of the outcomes of a study of middle-school students' use of mathematics to solve problems was the recognition of the five constituents of a mental model (Lesh et al., 2000). The first constituent is the *referents* of the model, the semiotic symbols used to represent the object. Referents can be either physical or mental objects, such as an equation, the number one, the sign used to represent addition, an atom or compound, a chair or a puff of air, or even emotions and intentions. Referents also include the symbols used to refer to the object such as names, written symbols, or graphic representations. The referents are the "elements" from which mental models are constructed.

The second constituent of a mental model is the *relationships* between or among referents. One relationship might be physical location. Another might be cause and effect. A third relationship might be host and symbiont. A fourth relationship might be as multiplier to multiplicand. As illustrated by these examples there are many other relationships that mental models can represent.

The third constituent is a set of *rules* or *syntax*. The rules dictate the relationship that referents must have in order for the relationship between them to have meaning. In mathematics, for example, 2 + 3 = 5 has meaning but +2 = 35 does not. In origami, one must make the folds in a specific order to obtain the desired outcome.

The fourth constituent is *results*. This constituent permits one to derive new knowledge from experience and mental activity. Results might be the answer to a mathematical equation, the products of a chemical reaction, or the genetic instantiation of prodigy.

The first four constituents are static in nature. The fifth constituent – *operation*, which acts on referents using relations and rules to produce results – is considered a dynamic constituent of a mental model. Examples of an operation might be the mental rotation of a molecule, mentally calculating the point of impact of an object shot into the air, balancing on a balance bar, and harmonizing with another singer. We cannot offer direct explanations for these activities. For this reason, it seems that the operation constituent of a mental model is knowledge located in an unheeded area of the mind. This use of the word unheeded follows from, "… we know more than we can tell" (Polanyi, 1983, p. 5). This is tacit knowledge that we possess but which we can not express directly.

As an example of the five constituents of a mental model, consider the mental rotation of the three-dimensional structure of an organic molecule. The referents are the atoms, bonds, colors, sizes, lengths, positions, angles, orientation, sequence, charges, properties, energy, and the molecule. Relations are left or right of a referent, above or below a referent, in front of or behind a referent, and the number of bonded neighbors. Other relations are angle with respect to another referent; position order in the chain or branch; and singly or doubly bonded. Some rules/syntax of rotation might be conservation of position, conservation of number of atoms, conservation of sequence, and conservation of atom identify. The operation is rotation. The results might be a mirror reflection of a molecule; a representation of the back side of the molecule; or a different orientation in space.

A Second Conceptual Basis for the Models and Modeling Perspective

The work of Case et al. (1996) provides another basis for a Models and Modeling framework. The objective of Case's work was the elaboration of the mental structures and processes that accounted for cognitive maturation of children. Case argued that mental models can be either local or global. Local mental models are constructed as needed and discarded after use, to be reconstructed if needed later; global models are maintained for a relatively longer time. One uses global models in situations that require benefit of experience while local models are usually invoked in situations that are algorithmic in nature (Briggs, 2004). Many circumstances require the cooperative use of both kinds of mental models such as braking to a stop after determining how far away is the other vehicle.

Whereas Lesh's "mental model" is composed of cognitive elements and operations that are distributed over heeded local and global cognitive sub-models, Case's approach allows us to deal with unheeded central conceptual structures and a central executive structure conceived of as controlling mental processes and decision-making. The two types of structures interact to produce new knowledge and facilitate the use of existing knowledge.

Theoretical Framework

A useful theoretical framework places its assumptions in view for practitioners (Crotty, 1998). Models and modeling has a set of assumptions that gives it a unique perspective on research activities. The ontological assumptions are that a real world exists outside of one's mind and one can know about that world by using the senses to gather information. Another assumption is that participants can articulate and think about their heeded thoughts and that both participants and researchers can infer, from the heeded thoughts, artifacts, and actions, a participant's unheeded thoughts. Kant (1952) argued that one can never know a thing in itself, that is, one can never know the true nature of something because one always views the thing through the filters of senses and experience. For example, if a participant says, "I think this looks like a mirror image of the molecule." and draws a correct artifact, one can infer that the participant has a working mental model of the reflection of light between an object and its mirror image. For this reason the researcher has to be aware of her or his assumptions and make them available for evaluation by the readers of the reported research. This allows the readers to determine if the conclusions of the research project are warranted.

In the realm of epistemology, Models and Modeling assumes that "knowledge is constructed in the mind of the learner" (Bodner, 1986, p. 873). If people have mental models then they must have constructed them from sensual and experiential information (Halloun, 1996). Another implication is relativity, or the possibility of constructing various mental models for the same concept (Starver, 1998), which explains the existence of preconceptions, misconceptions, and alternative conceptions, which exist side by side with domain-acceptable mental models.

One set of research questions is particularly amenable to the Models and Modeling paradigm. In qualitative research, one can take several perspectives. In a first-order perspective one might ask, "What is the world like?" A second-order perspective asks, "What is your experience of the world?" A third-order perspective asks, "What is your conceptualization of your experience of the world?" It is this third-order perspective and question for which both Models and Modeling and phenomenography (see Chapter 8) are particularly suited.

Thought-Revealing or Model-Eliciting Activities

The Models and Modeling paradigm makes extensive use of thought-revealing or model-eliciting activities (Lesh et al., 2000). This technique consists of creating carefully designed cognitive environments in which a participant must solve a problem by constructing a mental model of the problem, the solution path, and an outcome or result. A list of questions has been generated that a researcher might ask when designing a thought-revealing activity (Briggs, 2002, adopted from Lesh et al., 2000):

- Does the task put participants in a situation where they recognize the need to develop a mental model? To assure that the thought (model) eliciting activity puts the participant into this type of situation the researcher must pilot the task design and determine if the data stream will produce acceptable answers to the research questions. The piloting of the task will also contribute to confidence in the answers to the following questions.

- Is the problem fruitful, intelligible, and plausible?

- Does the problem statement strongly suggest appropriate criteria for assessing the usefulness of alternative solutions?

- Will the participants know when they are finished with the problem?

- Does the thought-revealing activity require participants to reveal explicitly how they are thinking about the situation by revealing the solution path they took?

- Does the problem provide a way of thinking that is shareable, transportable, easily modifiable, and reusable?

- Does the solution provide a useful prototype, metaphor or tool for interpreting other situations?

Other questions that should be considered in the design of a thought-revealing activity would include the following:

- Have instructions been made clear and do they solicit a clear outcome or result?

- Are all of the constraints of the problem explained clearly?

- Have confounding effects been considered? Have the identified confounding effects been eliminated or randomized throughout the research project.

Figure 1 is a representation of one molecule used in a thought-revealing activity by participants in a research project focused on mental molecular rotation.

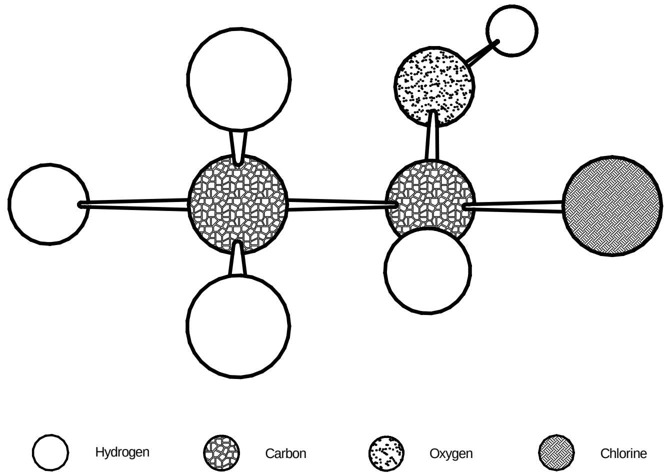

Figure 1. One of the drawings used as a thought-revealing activity of mental molecular rotation.

During the design of the molecule to be used in this thought-revealing activity, careful attention was paid to eliminating as many confounding principles as possible. For example, the molecule was placed with its long axis along the horizontal midline of the page. This was done to eliminate problems with visualization of the molecule that might be confounded with the ability to rotate the molecule from the starting position, shown in the figure to the required terminal position. Failure to visualize the molecule properly and transform the printed image into a mental image would preclude proper mental rotation of the molecule. For example, to assure that participants could transform the printed image into a mental image of the molecule, the coordinate system in the figure was aligned with the vertical and horizontal axis. Clues about perspective were incorporated into the figure to aid visualization and the production of a correct mental representation of the molecule. I wanted to avoid the situation in which a participant failed to rotate the molecule correctly because of a problem with their ability to recognize the spatial orientation of atoms in the molecule. In the figure used in the research project, the atoms were color–coded in standard chemistry colors to help participants keep track of the atoms as they were rotated. The molecule is composed of nine atoms to keep the cognitive load within the range of all of the participants. My research has shown that novice rotators try to keep track of each atom in a molecule as they rotate it. To ensure that participants could mentally rotate the molecule successfully I kept the total number of atoms to 30 or less. Each of these criteria was implemented to assure that the participants could recognize the need to rotate the molecule in some way and could talk about it while accomplishing the task.

Only after piloting the thought-revealing activity was I able to answer the list of questions mentioned above. The design of the task proved to be successful in that every participant in the mental molecular rotation project was able to see the need to represent the molecule mentally and rotate it to the required terminal position. The participants developed specific solutions to the tasks and were able to talk about their strategies, barriers, and techniques used to achieve the required terminal position of the molecules. The most important question seemed to be, “Does the thought-revealing activity require participants to explicitly reveal the solution path they took?” The participants did reveal their thoughts and this aspect of the task was vital to obtaining a fruitful, intelligible, and useful stream of data. The questions in the list assured that the thought-revealing activity design provided a successful data collection phase for the research project.

The Models and Modeling paradigm also requires a technique for capturing the conceptualizations of the participant. These conceptualizations are usually verbal in nature but can also encompass artifacts, computer key-strokes, and body gestures. For these kinds of data streams one might use video, field notes, and audio recordings.

A fruitful technique for assuring a useful data stream of participant conceptualizations is the think–aloud Protocol (Simon & Ericsson, 1993). This protocol is an interviewing technique in which the researcher introduces the thought-revealing activity and instructs the participant to talk continuously, during the activity, about the problem, the strategies for reaching a result, the solution path, any barriers to reaching a result, and the nature of the result. In addition, the researcher instructs the participant to talk aloud about ideas and concepts, definitions, and observations about the problem and the desired result. The researcher then transcribes the captured data stream for analysis.

The goal of analysis of data is the creation of new knowledge. Using the text and artifacts as data, the researcher can analyze for construction of models. One method of analysis that is congruent with the models and modeling paradigm is grounded theory (Strauss & Corbin, 1998). In this technique, participant conceptualizations identified in the text as codes are analyzed by, “… differentiation, abstraction, reduction, and comparison of meaning” (Svensson, 1997, p. 171). The codes from the data and artifacts are compared and contrasted in order to elucidate explicit components of the participants’ conceptualizations. The goal of the process is to “understand in a limited number of qualitatively different ways…” (Walsh et al., 1993, p. 1134) the participants’ constructed mental models. The researcher can then use the identified components of the participants’ conceptualizations to construct a representation of the participant’s mental model.

Examples of Research Using Thought-Revealing/Model-Eliciting Activities

Most of the examples of research studies using a mental models paradigm come from Math Education. Lesh et al. (2000) described research studies using three different thought-revealing activities: The Sears Catalog Problem, The Softball Problem, and The Million Dollar Problem. As a graduate student at Purdue University, I worked on a research project analyzing another thought-revealing activity, The Summer Jobs Program. Lesh and his graduate students have developed and used more than 20 thought-revealing activities that were implemented in research projects using the models and modeling theoretical framework.

One example of the use of the Models and Modeling framework in chemistry can be found in my work (Briggs, 2004). The primary research question for this study was “What are the structure and processes required in the mind of a participant to mentally rotate molecules?” The experimental design was a cross-case study of participants who were learning to mentally rotate molecules. Nine molecules were chosen as rotational tasks in the study. The molecules were printed as two-dimensional representations of the three-dimensional structures of these organic compounds. The task molecules were graded in difficulty by changing the number of atoms, the amount of branching, and the identity of the atoms. The tasks consisted of asking the participants to rotate the molecules along various axes and in combinations of axes.

Participants were drawn from two semesters of an organic chemistry course taught at Purdue University. Participants were invited to join the research study and were not given any compensation. Each student that applied for entry into the study was given the Purdue Visualization of Rotations Test (Bodner & Guay, 1997) because visualization is an important prerequisite for mental modeling, as has been addressed by Briggs and Bodner (2005). Five volunteers demonstrated sufficient ability to mentally rotate objects to participate in the study.

Each participant was interviewed three times over a 15-week period (one semester). Each interview took about 50 minutes and produced a ten-page transcript, on average. Each interview consisted of two tasks; each task asked for rotation of one of the molecules.

Twelve transcripts were obtained for analysis. Two interviews were not recorded due to equipment malfunctions, and one participant could not perform the requested rotation of a difficult molecule. The transcripts were treated individually, as a participant set, and as a study set (all participants, and all transcripts). In the following analysis, the set of transcripts from the study are summarized. During multiple passes through the transcripts, 140 codes were assigned to conceptualizations by the participants. During the analysis 34 unique codes were obtained by differentiation, abstraction, reduction, and comparison. The subjects (*conceptualizations)* of participants’ mental actions that had the same referent were grouped, and the name of the code was modified to indicate the nature of the referent. Participants are labeled R, C, O, and J. The three most frequently occurring codes are listed with the frequency (in parentheses), a definition, and a vignette from the transcripts.

Mental tool (79)

> A constructed model used to visualize a referent.
>
> A model used to operate on a referent.
>
> O: OK, that’s about as good as my brain is going to get it. One thing I noticed that I found myself doing at the end was for a lot of these hydrogens and a couple of the carbons that I was working on, on

the carbon chain, was thinking about the whole right side and actually gripping that oxygen bond, as if it were a stick figure, and then just feeling out, as I rotated, where that other atom was going to come. You see what I am saying?

I: Yes.

O: It would be almost as if I were turning the whole molecule physically in my mind. I was just sort of … and I would grip that other one [atom] in my other hand and it would just have to follow.

(This model was labeled the "crank—shaft model".)

Modeling (151)

Mental activity required to produce a representation.

The model contains cognitive elements, operands, and operations which reduce the complexity or increase the comprehensibility of the referent.

J: (Constructs a model of a reflection in a mirror.) … this is also kind of like a mirror reflection of what you are going to see on the other side … .

C: (Also constructs the mirror model.) I would imagine just flipping it over, based on a mirror.

(This mental model was labeled the "mirror model".)

Representation (175)

A change of structure from one medium to another.
Re-presentation of a referent in a new medium: such as a molecule drawn on paper or a physical molecular model or a mental image of a paper image.

The physical or mental model of a referent that can be transported from one place to another without moving the referent.

O: I'm finding that I'm using the triangle bonds which show coming out at me more [the symbols in the drawing] from my … I guess the way you show a bond going into the page. … mine are not very artistic so it's a little difficult to see ….

R: Then this carbon (carbon number one in the task statement) has three hydrogens attached. And those will be in a tetrahedral shape so I can just draw them in (on the drawn artifact).

(This code was assigned to relations and any methods of indicating the relation in a transformation from mental image to paper drawing.)

The objective of the code analysis was to unfold the referents, relations, results, rules/syntax, and operations which composed a mental model of mental molecular rotation. The outcome was a mental model of the way participants learned to mentally rotate molecular models. These results are consistent with our belief that the Models and Modeling paradigm can be used as an explanatory metaphor for learning.

Implications of Using a Models and Modeling Theoretical Framework

As noted previously, the Models and Modeling framework is useful for answering questions such as: “What are the mental structures and processes that allow …?” that are not amenable to quantitative research methods. Individuals who have struggled with computer software often conclude that “ease of use” and “power” seem to be mutually exclusive characteristics. In some ways, qualitative researchers experience the same phenomenon; their methodology is powerful but it is also labor intensive. The design phase of a research project must carefully consider the research questions and match them with the theoretical framework that is the most coherent and powerful. For the Models and Modeling paradigm to be successful, the thought-revealing activities that serve as its foundation must be carefully designed to produce clear conceptualizations. The participants should be chosen from a population that is currently learning the subject of the research project because as Minsky (1986), has said, “An idea will seem self-evident — once you’ve forgotten learning it!” (p. 128).

Because the Models and Modeling paradigm seeks to know how participants construct their mental models, the most effective time to interview them is during the process of model construction. The interview process must give the participant time to think, and iterative interviews are required to capture the construction process over time. The data stream must be captured and transformed into a text for analysis. The analysis requires multiple passes through the text searching for concepts that form the constituents of a mental model. The mental model must be assembled and then confirmed. Only after one performs each of these steps in the research can the mental model be obtained.

Despite the labor-intensive nature of this theoretical framework, it is useful for the class of research questions dealing with learning and knowledge construction. The use of this framework opens a window of research into knowledge, behavior, emotions, intentions, and opinions, but it may not be able to address questions of the structure and functions of the brain. Questions in chemical education that seek to illuminate how students learn and how instructors and teachers can facilitate learning are in the domain of models and modeling. For example, when we understand students’ learning processes, we are in a better position to teach students. As we discover the constituents of domain-specific mental models, we can facilitate students’ learning by showing them the mental materials, the referents, relations, rules/syntax, results, and operations that they can use to build mental models. Chemists have abundant theoretical and methodological frameworks for seeking the answer to questions such as which substituent is more effective in increasing the enantiomeric yield in an organic synthesis, Models and Modeling can provide answers to questions that deal with how a learner conceptualizes a substituent, the structure and properties of a molecule, and its reactions.

The models and modeling theoretical framework provides an explanatory metaphor of learning. It seems to be the best available description of the way students construct knowledge and can provide an evolutionary advance in our the knowledge of the thought processes of our students, which gives us a deeper understanding of mental activity and structure that is useful in teaching and learning. Results obtained from use of the Models and Modeling framework are compatible with many educational methods such as process-oriented guided inquiry learning (POGIL), discovery learning, inquiry learning, distance learning, and other models of instruction and learning. The framework can also inform instruction from lesson planning to curriculum design.

A theoretical framework is only as useful as its ability to explain a phenomenon and to predict future phenomena. The models and modeling theoretical framework has shown that it is capable of explaining the mental structure and processes required to rotate mentally a molecule. One last task is to show that the Models and Modeling paradigm can also predict the success or failure to rotate mentally a molecule and explain why such a prediction might be trustworthy. The process of transforming a representation, the dynamic operation, gives the paradigm the ability to predict outcomes of molecular rotation. If a participant has difficulty transforming a physical representation of a molecule into a mental representation of the molecule then no processing can take place and no result is possible. In this case, the participant must work on obtaining the static constituents of a mental model and using them to build a representation of the molecule.

If the participant can transform a physical model into a mental image but cannot operate on it properly, then a physical artifact might be drawn but would be incorrect. Another possibility is that the transformed, mentally rotated, molecule might be correct but the participant may not be able to draw the artifact due to lack of drawing ability. In this case a crude artifact might be produced that is essentially correct. Inspection of the artifact can determine which is the case.

If a participant can transform a physical artifact into a mental image and operate on the mental image correctly and then can produce a correctly transformed, that is, rotated artifact, then one can say the participant has a complete and working mental model of mental molecular rotation. In each case presented the instructor can determine the state of the mental model and facilitate the construction of the missing or immature constituents.

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5

Pedagogical Content Knowledge

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Biography

Matthew Miller is an Assistant Professor of Chemistry & Biochemistry at South Dakota State University, Brookings. He studied chemistry at the University of South Dakota, receiving a bachelor's degree in chemistry education in 1985. Later that year, he accepted a teaching position at Southwestern Wisconsin Community Schools in Hazel Green where he taught AP chemistry, introductory chemistry, physics, and physical science. In addition, he found time for coaching football, basketball, softball, and forensics (prose and poetry reading, play acting, group interpretive reading, oratory, etc.). Nine years later he enrolled in graduate school at Purdue University to study analytical chemistry and chemical education, completing a degree in those fields in 1998 and 2001, respectively. His dissertation study, under the direction of Mary Nakhleh, involved case studies of pre-service teachers and their struggle to construct pedagogical content knowledge while enrolled in the physical science methods course. In 2001, he accepted the faculty position at South Dakota State University where he continues to pursue his research interest in chemical education, specifically secondary science education. He currently teaches an introductory honors/majors chemistry course and the secondary education physical science methods course.

Introduction

Pedagogical content knowledge (PCK) was first described by Lee Shulman as a form of knowledge which connects a "teacher's cognitive understanding of subject matter content and the relationships between such understanding and the instruction teachers provide for students" (Shulman, 1986a, p. 25). Although not considered among the traditional frameworks for research in education, PCK offers a new perspective on research within the area of teacher education. As described by Patton (1990):

> The social and behavioral sciences have evolved into disciplines by focusing over time on different core questions. Those differences in focus have implications for the kinds of questions a particular researcher will ask and the scholarly tradition within which a specific study is placed. (p. 66)

PCK has provided researchers interested in studying teacher expertise with "… a new analytical frame for organizing and collecting data on teacher cognition" (Gess-Newsome, 1999a, p. 10). PCK allows researchers to focus on specific questions regarding teachers' knowledge and on appropriate methodology for answering those questions. PCK, therefore, can be considered a useful theoretical framework for qualitative research.

History of Pedagogical Content Knowledge

During the final decades of the 20th century, educators and politicians were engaged in an intense debate on science education in the United States. Many reports were issued describing the status of American schools, including reports from the National Commission on Excellence in Education (1983a, 1983b); the Carnegie Forum on Education and the Economy, Task Force on Teaching as a Profession (1986); the Holmes Group (1986); and the Southern Regional Education Board (1985). Each report specifically pointed toward the competency of teacher education programs as a potential reason for poor results in science education. Of particular concern was the limited amount of time spent on content knowledge during teacher preparation programs. The creation of standardized exams to assess teachers' content and pedagogical knowledge, mandated through the No Child Left Behind Act (2002), has tried to address these issues. However, some argue that creating standardized exams to assess teacher content and pedagogical knowledge does not measure the most important form of teacher knowledge. This type of knowledge, PCK, is a category of knowledge specifically constructed by teachers, yet distinctly different for each specific content area.

The initial model of PCK was developed and supported by studies related to a research project entitled "Knowledge Growth in a Profession" (Shulman, 1987; Wilson, Shulman, & Richert, 1987; Shulman, 1986b). Findings from this work labeled PCK as the specific teacher knowledge that allowed a teacher to transform content knowledge into a more conceptually understandable version for students. As explained by Shulman (1987), PCK results from the blending of content knowledge with pedagogical methods. Through this combination of knowledge, teachers gain a perspective that enhances their abilities to present specific topics in a specific subject area. Later it was proposed that teachers construct PCK not only by combining content and pedagogy, but also by combining these two knowledge categories with curricular, student, and contextual knowledge. The various forms or categories of teacher knowledge are summarized in Table 1.

Table 1. Categories of Teacher Knowledge.

Knowledge Category	Description
Pedagogical	Encompasses the general knowledge, beliefs, and skills about methods for teaching (Grossman, 1990).

Content	The facts, concepts, principles, and procedures taught about a respective subject (Gess-Newsome, 1999b).
Curricular	Understanding how particular concepts fit into the grade level at which it is taught (Grossman, 1990).
Student	The prior knowledge of students and how students will most likely enhance or change that knowledge (Grossman, 1990).
Contextual	Specific knowledge that is unique to the learning setting (Grossman, 1990).
PCK	An amalgam of content and pedagogy unique to a subject matter teacher. The blending of content and pedagogy into an understanding that allows the teacher to more thoroughly understand how to present a topic (Shulman, 1987).

Continued research in the area of teacher knowledge suggested that the acquisition of PCK was essential for teachers to provide proper instruction and improve conceptual learning by students (Gudmundsdottir & Shulman, 1987). Case studies showed that differences between novice- and expert-teachers' level of PCK resulted in differences in the quality of student learning. Additionally, PCK allowed teachers to conceptualize their own specific content knowledge and transform it into a form understandable to students (Gudmundsdottir, 1991). Effective teaching appeared to be linked to the quality of teachers' PCK.

The acquisition of PCK by teachers was considered critical because teachers were responsible for making concepts meaningful to students (Grossman, 1990). According to Grossman, this acquisition of PCK could result from a variety of experiences during the overall career of a teacher. PCK construction might occur during apprenticeship of observation activities (student teaching/internships), disciplinary background instruction (content courses), experiential learning (in the classroom), or professional coursework (education courses).

A slightly different view of PCK was developed by Cochran, DeRuiter, and King (1993). These researchers believed that the word *knowledge* in PCK was too static for the constructivist perspective. PCK should be thought of as a versatile form of knowledge which required continual change to meet the needs of students. Shulman's view of PCK inferred a stagnant production of knowledge that, once constructed, did not change. To establish the point that PCK was a continually changing construction of knowledge, these researchers replaced the word *knowledge* in PCK with *knowing* because PCK required active involvement of this knowledge in a continually changing classroom environment. Stengel (1997) provided support for this alternative view. According to Stengel, the concept of PCK is less effective if teachers forget that knowledge is constructed through active learning. If teachers become satisfied with their current knowledge and stagnant with respect to continuing education, their teaching knowledge will become less effective. PCK must be thought of as an ongoing, ever-changing entity that is only maintained through continuous activity.

This changeable nature of PCK makes it difficult to pinpoint specific constructs of this category of knowledge. Teachers, as learners, construct their own knowledge, resulting in many individual examples of PCK. Additionally, because of the numerous categories of knowledge that may be integrated into PCK, differences in PCK constructs between instructors will likely exist. Finally, as described by Stengel (1997), PCK results from active learning, allowing PCK to change to fit the needs of individual instructors.

Assumptions of Pedagogical Content Knowledge

PCK as a Category of Knowledge

Several assumptions are made when considering pedagogical content knowledge as a category of knowledge. First, it is assumed that teachers become experts in a specific subject area through construction of specific knowledge that informs them of superior teaching methods for that subject, ultimately assuming that a particular method of teaching is more effective toward teaching a specific topic. Second, researchers assume instruments can be devised to identify and measure PCK. Third, it is assumed that PCK can be shared with other science educators for use in their classrooms. Finally, it is assumed that articulations by teachers about beliefs and knowledge mirror teacher practice in the classroom. In this section, I will examine the validity of these assumptions.

Before exploring these assumptions, however, it may be helpful to provide several examples of teacher PCK. One example of PCK is taken from a study by Coll and Treagust (2002). In this work, student explanations of covalent bonding were elicited. The data showed that students at all levels, secondary through graduate students, rely on relatively simplistic mental models to explain covalent bonding. A comparison of curricula across these levels showed that a number of bonding models were used by instructors to teach covalent bonding, yet students continued to use the octet rule as a basis for explanation rather than using more robust models. The authors therefore suggested that teachers carefully analyze their curricula and utilize models that will provide students with information they will most likely use to explain concepts. At the secondary level, it would be most beneficial to focus on the principles of the octet rule because students at this level generally fail to utilize the more complex theories in their explanations, even when these models are presented by instructors. At the undergraduate and graduate levels, valence bond, molecular orbital, and ligand field theories should be introduced to increase the complexity of student understanding of covalent bonding. This is an example of PCK because content knowledge, pedagogy, and curricular knowledge are integrated into a concept about teaching covalent bonding.

The work of Frykholm and Glasson (2005) provides another example of PCK because it shows the integration of pedagogical knowledge with content knowledge across several content areas, specifically biology and mathematics. A student teacher monitored during the study stated:

> I presented a way that the students could predict how many incubation periods it would take for every student in the room to get infected. I thought this would be a good way for students to see how scientists use mathematical models to predict the spread of disease. (Frykholm & Glasson, 2005, p. 136)

From these two examples, we can observe the nature of PCK. Concepts from different categories of knowledge are combined to create a teaching concept that more effectively promotes student learning.

PCK has been identified as teacher knowledge that empowers teachers to help students construct appropriate content knowledge. Yet, our first assumption is that identifying PCK will yield knowledge about how to teach specific concepts to all instructors. For example, in drawing the conclusion in the PCK example presented by Coll and Treagust (2002), we assume using the octet rule exclusively in the secondary level represents the best approach for teaching secondary students. But if PCK is a personal transformation of knowledge into a form that best enables students to learn, then PCK will have different configurations for individual instructors, and generalizations such as those from the example above may not work best for all instructors.

A second assumption is that identifying and measuring teachers' PCK can be accomplished using instruments designed for such purposes. The methodology currently used to measure PCK generally requires teacher articulation of personal beliefs about teaching during multiple experiences. For example, in a study by Miller (2001), changes in pre-service teacher PCK were monitored through using concept maps, interviews, journaling, and other classroom writing activities. The concept maps were used to identify changes in content pedagogical knowledge during a physical science methods course while the interview, journaling, and assorted classroom writing were used to elucidate reasons for changes in content and pedagogical knowledge. PCK was identified by analyzing the statements of pre-service teachers as they discussed changes made on concept maps. In a study by Van Driel and Verloop (2002), semi-structured interviews identified teacher knowledge with respect to models and modeling in science. Information from the interviews was used to construct questions for a Likert-type survey designed to reveal perceptions regarding teaching activities, student knowledge, and modeling. Yet, due to the nebulous nature of PCK, using multiple methods to identify PCK may not successfully accomplish the goal of identifying and measuring PCK. For this reason, no specific measures are available for identifying or quantifying PCK.

A third assumption regarding PCK as a category of knowledge is the ability to share PCK between educators. Instructors construct their own personal PCK, but the ability to embrace examples of PCK from others through continuing education opportunities may not be a practical process. The personal nature of PCK construction would suggest that PCK constructed by one instructor may not be designed for use by another.

Finally, do teachers' beliefs and knowledge actually influence classroom practice? It is assumed that what the teacher believes and knows about teaching automatically becomes utilized in the classroom. Yet, many teachers quote constructivist ideas but fail to support those ideas with constructivist methods. Therefore, the assumption that teacher articulations of beliefs and knowledge represent actual teacher practice is questionable.

PCK as a Theoretical Framework

The use of PCK as a theoretical framework is based on a series of assumptions:

- PCK represents a category of teacher knowledge that is the essence of an expert teacher.
- PCK provides a framework that can be used to describe the origin of this critical teacher knowledge, i.e., that PCK represents an epistemological approach to constructing teaching knowledge.
- PCK is a constructivist process and therefore a continually changing body of knowledge.

It is now a widely accepted belief that PCK represents the essential knowledge needed for a novice teacher to mature into an expert. Shulman's (1987) vision of teacher knowledge as an "amalgam" of knowledge has focused many teacher education programs on creating new activities that engage pre-service teachers. This same vision also provides a focus for educational research. Unfortunately, PCK remains a nebulous category of knowledge that is difficult to isolate and study.

PCK provides researchers with a starting point for collecting and analyzing data regarding teacher knowledge. It embodies an epistemological approach to understanding teacher knowledge because it articulates the central components of that knowledge, laying a pathway to find improved methods for teacher preparation. Through continuing PCK research, researchers may soon outline methods teachers may use to construct important teaching concepts.

Finally, as a constructivist endeavor, PCK is a continuously changing unit. Researchers must be aware of the sinuous nature of PCK, being careful not to influence teacher knowledge during data collection methods. The ever-changing nature of PCK challenges the researcher to consider longitudinal methods to determine the impact of experience on PCK.

Methodologies/Analysis of Research on PCK

The use of PCK in research and the methods of data collection and analysis that result will be separated into two components: research on PCK and research using PCK as a theoretical framework. The basic difference between these distinctions is the first involves trying to identify or measure PCK while the second utilizes the assumption that PCK exists to examine other aspects of teaching science.

Research on PCK

Many studies have been conducted to identify aspects of PCK. A few examples of PCK studies are shown in Table 2. Current research on PCK involves the use of methodologies in one of three classifications: 1) convergent and inferential techniques; 2) visualization techniques; and 3) multi-method evaluation (Baxter & Lederman, 1999). These techniques have been used to identify PCK constructs, how these constructs were constructed by teachers, and how these constructs influence student learning in the classroom. In the following sections, each of these classifications will be discussed using examples and criticisms to illustrate differences between them.

Table 2. Examples of PCK Studies in Chemistry/Science Education

References	Research Questions/Purposes
Basista & Mathews, 2002	How do integrated science and mathematics professional development programs enhance teachers' content and pedagogical knowledge?
Carpenter, Fennema, & Franke, 1996	How does understanding students' thinking connect teachers' PCK to subject matter, curriculum, and pedagogy?
Clermont, Krajcik, & Borko, 1993	How do intensive chemical demonstration workshops impact novice teacher PCK?
De Jong, Ahtee, Goodwin, Hatzinikita, & Koulaidis, 1999	What PCK do pre-service science teachers have regarding the teaching of combustion?
Fernandez-Balboa & Stiehl, 1995	How do professors transcend their status from "subject matter knowers" to "subject matter teachers"?
Frederik, Van Der Valk, Leite, & Thoren, 1999	What conceptual difficulties about temperature and heat do pre-service teachers have and what difficulties do they expect their students to have?
Frykholm & Glasson, 2005	What are pre-service science and mathematics teachers' perceptions of their content and PCK with respect to connecting science and mathematics instruction?
Grayson, 2004	How does concept substitution enable teachers' to identify student difficulties?

Halim & Meerah, 2002	What is science trainee teachers' awareness of pupils' likely misconceptions and how do these teachers suggest explaining scientific ideas to pupils?
Irving, Dickson, & Keyser, 1999	How do professional development courses enhance secondary teachers' content and pedagogical knowledge?
Lowery, 2002	How do pre-service teachers construct PCK of elementary mathematics and science and what is the extent of that knowledge construction?
Major & Palmer, 2002	To what extent does college faculty think about student learning?
Margerum-Leys & Marx, 2004	How is knowledge of educational technology acquired, employed, and shared by the participants?
Penso, 2002	How and to what extent does a teaching practice in schools contribute to the acquisition and growth of PCK?
Sweeney, 2003	What are the articulated personal practice theories of a beginning high school chemistry teacher?
Thiele & Treagust, 1994	Why did teachers choose to use analogies in chemistry and what variations between teachers existed?
Treagust & Harrison, 2000	What is the role of explanations in science instruction?
Twiselton, 2000	What are the knowledge constructions of student teachers and what types of knowledge do they see as important in their teaching?
Van Der Valk & Broekman, 1999	How does lesson preparation demonstrate PCK?
Van Driel & Verloop, 2002	What is experienced science teachers' knowledge of teaching and learning models in science?
Veal, 2004	What is the relationship between chemistry teachers' beliefs in teaching and PCK?
Viiri, 2003	How well do teachers' know their students' conceptions of moments of force?

Convergent and Inferential Techniques

Convergent and inferential methods involve the use of pre-determined verbal descriptions of teacher knowledge categorized as PCK. These descriptions are organized in the form of Likert-scale surveys or pre-/post-assessment, multiple-choice/short-answer tasks to assess teacher recognition of pre-described PCK. Data are analyzed to assess the level of awareness teachers have with respect to pre-described knowledge. Comparisons between teachers exhibiting or not exhibiting PCK can then be made to assess the importance of acquired PCK on student learning.

Examples of the use of convergent and inferential methods can be used to further explain this methodology. Viiri (2003) used a short-answer questionnaire to assess student knowledge of moments of force. The questionnaire was constructed from prior research regarding difficult concepts for students studying moments of force (Rowlands, Graham, & Berry, 1998). Experienced teachers were given the same questions and asked to predict their students' answers and provide reasons these answers would be chosen by their students. The students' answers and teachers' predictions were compared to assess experienced teachers' awareness of student difficulties with moments of force. Additionally, teachers were shown student questionnaires and their reactions to students' answers were observed, providing further evidence of teacher awareness. This study provides an example of identifying PCK because two categories of knowledge — content and student — are being analyzed with respect to what experienced teachers know about how their students will answer specific content questions.

Halim & Meerah (2002) utilized previously-written short-answer questions involving basic concepts in physics, for which there are known misconceptions, to survey pre-service teachers' PCK. Pre-service teachers were asked to explain the physics concepts as if they were going to address an audience consisting of secondary students. The explanations were written and submitted to the researchers. Since the physics concepts chosen for the survey were known to involve student misconceptions, responses from pre-service teachers provided evidence of trainee teachers' awareness of these misconceptions. The degree of teacher awareness provided information as to pre-service teacher knowledge of student misconceptions. Therefore, references to known misconceptions were counted as evidence of pre-service teacher PCK because this represents integrating teacher's knowledge of what students perceive with their specific content knowledge.

A final example of convergent/inferential methods is a study by Basista & Mathews (2002). These researchers used pre- and post-testing to assess content knowledge changes resulting from participation in a workshop. Assessments of teacher knowledge were statistically analyzed to identify changes in teacher content knowledge. Additionally, pre-workshop, post-workshop, and post-teaching Likert-scale/short answer questionnaires were used to determine the impact of the workshop on teacher pedagogy, opinions, and confidence regarding the content knowledge following their participation in the workshop. Statistical analyses of teacher responses were used to identify connections between the impact of the teacher workshop on content knowledge and change in teacher pedagogical approaches toward teaching the content. In this example, the analysis provided information about how changes in content knowledge influence pedagogical decisions, therefore an example of teacher PCK.

Criticism of Convergent and Inferential Methods. Convergent and inferential methods have been criticized for several reasons. First, multiple-choice and short-answer exams designed to measure teacher knowledge assume the existence of a correct answer which is inconsistent with the concept of PCK. It is difficult to justify the “correct” PCK because the correct method of teaching specific content may be based on personal intuition. Therefore, the ability to measure teacher PCK using specific knowledge-based methodology such as multiple-choice or short-answer instruments may be inhibited by an inability to identify the many perspectives that may exist regarding how science concepts are taught (Baxter & Lederman, 1999).

Another criticism of convergent and inferential methods relates to the criterion-related validity of multiple-choice or short-answer exams for teachers. The problem with multiple-choice questions is that they may not be legitimate measure of the specific skill being analyzed by the researcher, thereby resulting in faulty information about teacher knowledge and, in this case, PCK. Questions exist as to the ability of these exams to effectively measure specific skills for teachers (Haertel, 1991). Considering the difficulty in establishing specific examples of PCK, writing questions that meet validity standards would be difficult.

Finally, standardized statements may not accurately depict the perceptions of a teacher regarding personal views about teaching (Kagan, 1990). The construction of these statements requires the transformation of teacher articulations into homogeneous constructs for such exams. The generalization of personal views of teaching makes it difficult to construct examination questions which explicitly match the views of all teachers.

Visualization Techniques

Visualization techniques are often used to analyze teacher knowledge, including PCK. Techniques such as drawing concept maps, using vignettes, and constructing analogies are examples of methods that provide illustrations of teacher perspectives. The use of visualization techniques by PCK researchers provides a physical representation of teacher knowledge. These physical representations can then be monitored for changes which may result when teacher knowledge is challenged during various activities and workshops.

Novak and Gowin (1984) have argued that concept maps provide visual representations of an individual’s knowledge. The use of tools such as concept maps allows researchers to create concrete representations of knowledge which can be monitored over time, yielding longitudinal assessments of knowledge changes. Changes in physical representations are assumed to provide evidence of teacher knowledge change.

Miller (2001) used concept mapping to analyze the construction of pre-service teacher PCK during a science methods course. Teachers were asked to construct a concept map containing terms important to one specific unit in a chemistry course that was the focus of numerous teaching activities throughout the science methods course. The teachers' concept map was reviewed periodically throughout the next year while the pre-service teacher was enrolled in a second science methods course (in the fall) and in a student teaching practicum (in the spring). Changes in the structure of the concept map were related to changes in the personal knowledge of that student. The researcher analyzed the data to connect these changes in knowledge with activities that may have influenced the changes.

In addition to the concept maps on specific content knowledge, pre-service teachers were also asked to draw concept maps of teaching pedagogy and of student difficulties related to the specific unit. These concept maps represented the teachers' knowledge of pedagogy and students with respect to the chemistry unit. Changes made to these maps were also connected to activities which may have influenced these changes. Overall, the concept-mapping exercises allowed the researcher to monitor the changes made in pre-service teacher knowledge as a result of experiences during the year in question (Miller, 2001).

The construction of PCK by teachers has also been assessed by using vignettes as visualization techniques. Vignettes are short, descriptive stories specifically written to describe specific activities. Veal (2004) used carefully designed vignettes containing pedagogical issues (classroom management, student learning, teaching styles), inaccurate science content, and questionable teaching methods to provoke conflict in the teachers' knowledge. A microgenetic method was utilized by the researcher in which participants in the study were exposed to the same stimulus at various times during the study. In this case, teachers were asked to read a vignette and respond to a set of questions at different times during a secondary science curriculum course and during student teaching field experiences. Over the course of a year, the teachers had multiple experiences with the same vignette, allowing the researcher to monitor cognitive conflicts through interview responses, observations, and coursework documentation.

Analogies are another example of visualization techniques that have been used to monitor PCK construction by teachers. Thiele and Treagust (1994) were interested in analyzing how teachers use analogies when teaching content in chemistry, specifically energy, reaction rates, and equilibrium. The researchers observed actual classroom use of analogies, audio-taped their use, and then carefully analyzed each analogy to identify the purpose for the use of the analogy. The analogies provided the researcher with an illustration of the teacher's knowledge structure regarding the specific content. Analysis of the analogies included categorizing the analogies as to why they were, what evidence of spontaneity existed for their use, and how similar analogies vary across teachers. On the basis of additional data that included observation notes, student work, and teacher materials, assertions were made as to why the analogies were used by teachers. A picture of teacher PCK was then constructed from these assertions.

Card-sort tasks represent another visualization technique used to assess teacher PCK. Gess-Newsome & Lederman (1993) used card-sorts and concept maps to allow teachers to organize their knowledge about teaching their primary content area. Participants were asked “What topics make up your primary teaching content area?” and then asked to use these topics to diagram the content area. Participants were allowed to diagram using a method of personal preference, and card-sort methods were an example of a chosen format. Participants were asked to create the card-sort diagram four times throughout one year. Changes in the structure of the diagram, along with interview data, provided documentation of knowledge changes. Data were analyzed to observe noticeable patterns among all participants.

Criticism of Visualization Techniques. Several criticisms can be offered regarding the use of visualization techniques to analyze PCK. First, to what extent can visualization techniques be expected to mirror the structure of knowledge within an individual’s mind? The use of concept mapping to assess PCK, for example, assumes that the map constructed by an individual represents the knowledge of that individual with respect to the corresponding content knowledge. Is this technique reliable at representing all that an individual knows with respect to the content knowledge being assessed? Additionally, the use of this visualization tool may also stimulate knowledge growth of the content being studied, so careful analysis of the degree to which this occurs should also be considered (Baxter & Lederman, 1999). In the future, a study might be done that involved careful training of participants with respect to the visualization tool followed by analysis of the degree to which an individual is able to completely diagram their knowledge of a specific subject.

Kagan (1990) voiced criticism concerning the length of time knowledge changes monitored by visualization techniques persist. The techniques discussed in the prior section — concept mapping, vignettes, analogies, and card sorts — typically represent changes in knowledge that occur during the assessment period. Unfortunately, changes in teacher knowledge can be short-lived if not reinforced when teachers return to the classroom, so the visualization techniques might only monitor short-term changes. Additional research is needed to study how long these changes last in the real world of teaching and to develop visualization techniques that might provide assessment of knowledge change over a longer period of time.

A final criticism of visualization representations is that they are ambiguous in nature. Several individuals may construct similar visualizations, yet these visualizations may represent entirely different knowledge constructs (Phillips, 1983). Researchers may be able to address this issue by standardizing representations made while using visualization techniques. However, training participants to use specific representations to describe similar concepts, although helpful in the assessment process, will likely impact the participants’ knowledge structure, changing it as the visualization technique is being used to assess that knowledge. In doing so, this assessment technique would now be acting as an intervention causing changes knowledge. This would diminish the effectiveness of the visualization technique as a method of analyzing PCK.

Multi-method Analysis

The most frequently used method of data collection and analysis for PCK research involves collecting multiple sources of data. In addition to visualization and convergent/-inferential methods, interview responses, observations, reflections, and course materials are often analyzed by researchers to establish perspectives on teachers' knowledge structure. Due to the ambiguity discussed regarding visualization methods and the questionable validity of using standardized assessments to identify PCK, triangulation of data sources is useful to validate research conclusions. Examples of the use of multiple methods in PCK studies will be provided in this section.

Large group discussions, small group collaborations, observation notes, written responses to classroom questions, journal entries, group presentations, unit plans, and lesson plans were data sources for a study by Frykholm and Glasson (2005) in which they analyzed the perceptions of pre-service teachers regarding content and PCK construction. Data analysis involved an iterative coding process of each type of data using a core set of themes. Following the coding process, an analysis was conducted to determine any relationships that existed across codes. The multiple layers of data provided opportunities for researchers to identify duplications in participant statements, thereby establishing the validity of the data.

In another example of multiple methods, Van Driel and Verloop (2002) used semi-structured interviews to identify teacher knowledge with respect to models and modeling in science. Information from the interviews was used to construct a Likert-type questionnaire. The interviews provided categories for which specific questionnaire items were constructed. The items were designed to ask teachers about teaching activities and student knowledge with respect to models. The questionnaire was taken by participants in the study at the beginning of an in-service workshop. The teachers' responses to these questionnaires were then analyzed to assess their knowledge of models.

A final example of the use of multiple methods involves using lesson plans, questionnaires, and interviews to identify characteristics of pre-service teachers' views regarding the teaching of combustion (De Jong et al., 1999). All participants were asked to construct a lesson plan for the first teaching opportunity of combustion in their classroom. Following the planning of their lesson, participants completed an open-ended questionnaire about their expectations of student preconceptions of combustion and why they chose the teaching approach described in the lesson. Finally, pre-service teachers participated in an interview in which they were verbally prompted to explain their lesson, the difficulties they expected students to encounter, and why the particular pedagogical approach was chosen. The analysis of each data set was conducted to categorize responses in pre-determined categories.

Criticism of Multi-method Analysis. The use of multiple methods of data collection to assess teacher PCK can be questioned because of the variety of opportunities provided for teachers to reflect on the construct of particular concern. Each added layer of data collection provides additional opportunities for the participant to consider what they know about a topic and change that viewpoint. Although additional data sources provide opportunities for triangulation, they also provide opportunities for reflection and knowledge change. Multi-method analysis will likely have an increasingly larger impact on changing knowledge with each added dimension to the project, thereby potentially biasing the findings of the study.

Using PCK as a Theoretical Framework in Research

Studies using PCK as a theoretical framework are not as numerous as those seeking to characterize examples of PCK. Several examples are shown in Table 3. A select few will be discussed further in this section.

Table 3. Examples of research studies using PCK as a theoretical framework.

References	**Nature of the Study**
Fottland, 2004	Pre-service teachers need to draw on experiences to connect theory; therefore, narrative of other teachers provide PCK learning opportunities.
Garcia, 2004	Teacher knowledge known as “desirable content knowledge” (Porlán & Rivero, 1998) consists of a network of metadisciplinary, disciplinary, and experience-based knowledge.
Halai, N. & Hodson, D. 2004	Teachers construct appropriate learning experience for students by drawing on a wide array of knowledge also referred to as “personal practical knowledge” (Connelly & Clandinin, 1985).
Hipkins & Barker, 2005	PCK is a form of teacher knowledge which connects complex structures, including knowledge of the nature of science: “NOS PCK” (Abd-El-Khalick & Lederman, 2000).
Hogan, Rabinowitz, & Craven III, 2003	PCK is useful in analyzing the complex interaction between teachers’ understandings of content and pedagogy and the influence this has on classroom instruction.
Johnson, 2006	Teachers face three dimensions and barriers — technical, political, and cultural — while engaging in standards-based instructional practices.
Kreber, 2004	Teachers engage in three types of reflection — content, process, and premise — across three domains of knowledge — instructional, pedagogical, and curricular.

Kreber (2004) utilized PCK as a theoretical framework in a study to analyze the degree and type of reflection higher education instructors devote to teaching. The work was based on the belief that reflection on teaching occurred in nine dimensions. These dimensions resulted from instructors' reflecting on content, process, and premise while considering three domains of knowledge: instructional, pedagogical, and curricular. This nine-dimensional view established the methodology as the researcher conducted an interview in which questioning was intentionally designed to elicit responses in each of these dimensions.

The concept of "desirable content knowledge or DCK," as initially reported by Porlán & Rivero (1998), was the basic framework of a study by Garcia (2004) to analyze the results of a specific educational strategy in Spain designed to convey a mode of teaching described as a "teacher investigator" to novice teachers. The goal was to engage teachers in activities promoting the teacher as a guide to student learning. This framework specifically identified three categories of knowledge teachers must integrate to construct desirable content knowledge: metadisciplinary, disciplinary, and experience-based knowledge. The methods used in this study included interviews and the collection of course documents to produce a case study for each participant. These methods were a direct implication of the DCK theoretical framework as in-depth data were needed to extract information about teacher knowledge constructed during the educational strategy.

In the final example, Hogan et al. (2003) utilize PCK as a theoretical framework in a meta-analysis study of novice and expert teachers to establish teacher representations of certain aspects of a classroom. In this study, PCK was viewed from a cognitive science perspective as an outline for identifying the basic processes of teacher problem solving. One outcome of the study showed that a major methodology used included three main components: curriculum planning, instruction, and the perception and reflection classroom activities. A general theme appears to be the need for reflective data collection methods to draw out teacher perceptions and identify the basic processes to teacher knowledge construction.

Conclusion

PCK is a complex form of teacher knowledge needed by teachers to convey their understanding of specific content knowledge using multiple methods that enhance student understanding and achievement. Much of the research involving PCK has been conducted to identify and characterize PCK, and the teacher education community continues to call for studies to devise methods for measuring PCK. However, PCK represents much more than a category of teacher knowledge; it also provides a starting point for research involving teacher education. As a theoretical framework, PCK provides a process for organizing this important research. The inclusion of PCK in this book on theoretical frameworks is an important step towards increasing its use in this role.

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