CHAPTER 1

Philosophical, Cognitive, and Sociological Roots for Connections in Chemistry Teaching and Learning

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INTRODUCTION

This chapter reviews some of the rationales for teaching chemistry in a connected manner. Three different approaches are considered, with specific examples from the recent chemistry education literature. The first rationale comes from philosophy, where knowledge requires connections among experience, inquiry, and the material. A rationale for connected teaching in chemistry also arises from psychology, specifically by considering how students’ cognition allows them to construct meaning. And finally, since learning is about the learner’s relationship with society, sociological issues arise because of goals of inclusion and diversity in the enterprise of teaching chemistry.

Through all of this, I will try to relate the different points of this discussion to particular contemporary ideas in chemistry and science education. As such, all of the work can be summed up by the following rationale for inquiry teaching, taken from the National Research Council report Inquiry and the National Science Education Standards (National Research Council 2005):

Through meaningful interactions with their environment, with their teachers, and among themselves, students reorganize, redefine, and


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replace their initial explanations, attitudes, and abilities. An instructional model incorporates the features of inquiry into a sequence of experiences designed to challenge students’ current conceptions and provide time and opportunities for reconstruction, or learning, to occur.

Instructional models … seek to engage students in important scientific questions, give students opportunities to explore and create their own explanations, provide scientific explanations and help students connect these to their own ideas, and create opportunities for students to extend, apply, and evaluate what they have learned.

THE EPISTEMOLOGY OF CONNECTION

To start our inquiry, we step back and consider where these ideas come from by going back to one of the most fundamental ideas in teaching: Socratic teaching, presented in Plato’s *Meno* (1961). On its surface, *Meno* is a dialogue about the teaching and learning of virtue or, rather, the problem that it seems to some that virtue cannot be taught because virtuous people do not always have virtuous children. To discuss this Plato presents a discussion of how learning occurs generally, through the agency of Socrates’ questioning a slave boy about a simple mathematical problem: the length of the side of a square with an area of 8. Socrates uses questions and some simple illustrations, eliciting explanations, predictions, and conclusions from the boy. Prior to the beginning of this excerpt, Socrates has guided the boy to indicate that a square that has sides of 2 ft has an area of 4 ft (Fig. 1.1a).

*Socrates:* And how many feet is twice two? Work it out and tell me.
*Boy:* Four.
*Socrates:* Now could one draw another figure double the size of this, but similar, that is, with all its sides equal like this one?
*Boy:* Yes.
*Socrates:* Now then, try to tell me how long each of its sides will be. The present figure has a side of two feet. What will be the side of the double-sized one?
*Boy:* It will be double, Socrates, obviously.
*Socrates:* You see, Meno, that I am not teaching him anything, only asking. Now he thinks he knows the length of the side of the eight-foot square.
**Meno:** Yes.

**Socrates:** But does he?

**Meno:** Certainly not.

**Socrates:** He thinks it is twice the length of the other.

**Meno:** Yes.

**Socrates:** Now watch how he recollects things in order—the proper way to recollect. You say that the side of double length produces the double sized figure? It must be equal on all sides like the first figure, only twice its size, that is, eight feet. Think a moment whether you still expect to get it from doubling the side.

**Boy:** Yes, I do.
Socrates: Well now, shall we have a line double the length if we add another of the same length at this end?

Boy: Yes.

Socrates: It is on this line then, according to you, that we shall make the eight-foot square, by taking four of the same length?

Boy: Yes.

Socrates: Let us draw in four equal lines using the first as a base. Does this not give us what you call the eight-foot figure? (Fig. 1.1b)

Boy: Certainly.

Socrates: But does it contain these four squares, each equal to the original four-foot one?

Boy: Yes.

Socrates: How big is it then? Won’t it be four times as big?

Boy: Of course.

Socrates: And is four times the same as twice?

Boy: Of course not. (Fig. 1.1c)

Socrates: What do you think, Meno? Has he answered with any opinions that were not his own?

Meno: No, they were all his.

Socrates: Yet he did not know, as we agreed a few minutes ago.

Meno: True.

Socrates: But these opinions were somewhere in him, were they not?

Meno: Yes.

Socrates: So a man who does not know has in himself true opinions on a subject without having knowledge.

Meno: It would appear so.

Socrates: At present these opinions, being newly aroused, have a dreamlike quality. But if the same questions are put to him on many occasions and in different ways, you can see that in the end he will have knowledge on the subject as accurate as anybody’s.

Meno: Probably.

Socrates: This knowledge will not come from teaching but from questioning. He will recover it for himself.

Meno: Yes.

Socrates: And the spontaneous recovery of knowledge that is in him is recollection, isn’t it?
Here and elsewhere in the dialogue, there is no place where we can find Socrates providing direct instruction in the form of “here is the answer.” But the boy does come to the correct answer. In the dialogue, Socrates draws the conclusion that the boy must have already known the answer, remembered from a previous life since he had not learned it in this life. To avoid a recursion problem, Plato also asserts that the knowledge does get a start, though through divine inspiration, not from the world, at some point in the soul’s journeys through the world.

The knowledge theory of *Meno* represents a “myth of remembering,” and it is pretty clear that this remembering was what Plato really believed, along with a belief in reincarnation. This is somewhat surprising, then, to find Socratic teaching so popular now, since it is unlikely many believe in reincarnation, including the specific memory of knowledge from previous lives.

However, if we look a bit closer, we can see something else embedded in the dialogue. As the quotation illustrates, Socrates does not “tell,” but he does “guide” the boy to look at and to do certain things, including constructing diagrams of a particular type. The boy is not a blank slate from which Socrates draws remembered knowledge. It is true that the knowledge does come from inside the boy’s head. But it is knowledge that originates in an attempt to explain the features of the world. This knowledge is then tested by making predictions about the world, observing results, and, when the prediction fails, revising the explanation. While Plato may tell us that this is a result of remembering, it is easy for us to see this process as one in which experience, not memory, is the source of knowledge.

Thus, this interpretation of *Meno* (and analysis of Socratic teaching) is that we do not come to know about the natural world through divine inspiration or by conjuring memories of an earlier life. Rather, we come to know because of deliberate and guided experiences with the world, including specific testing of theories and predictions.1

For more than two millennia after Plato, the philosophical discussion of epistemology focused on how to get at truth, generally taken to be

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1The reader should know that for Plato, experience could be a teacher, but because we only experience specific things, it could never be trusted. That prejudice is, perhaps, why Plato formulated the myth of remembering and of divine inspiration, since the divine was eternal and universal, in contrast to the unreliable experiences of our world. Aristotle, in contrast, did introduce and use an epistemology that gave priority to perception and experience as necessary precursors to the understanding of abstract principles (Scott 2007). Aristotle did not give us a script for teaching in the way Plato did with the *Meno*. 
a single thing that was, in theory, attainable by inquiry. Whether this
derived from empirical or idealist perspectives did matter, but the idea
of a single outcome for inquiry, properly done, was unquestioned, at
least in the Western traditions. Even the seeming overthrow of theistic
perspectives in the Enlightenment only gave rise to ideas that sought
to locate the discovery of truth as outside of revelation. It was not until
the growth of scientific materialism, in particular spurred by Darwin’s
theory of descent by natural selection, that questions of removing a
fixed truth from epistemology seemed possible, including the work of
the American pragmatist movement. This was summarized in the lec-
tures that William James gave on the subject. In these lectures, he
makes clear that truth is rooted in how the knower sees a given propo-
sition or method as useful to achieve an object of value.

As he put it in his lecture “Pragmatism’s Conception of Truth,”
“True ideas are those that we can assimilate, validate, corroborate, and
verify. False ideas are those that we cannot.” And, shortly later, “The
truth of an idea is not a stagnant property inherent in it. Truth happens
to an idea. It becomes true, is made true by events.” This, though,
invites a further question: What events can make something true? To
answer this, James reflects at length on two realities that constrain
thought: the realities of matters of fact and the realities of ideal rela-
tions as they can be formulated by the mind; events in our experience
of the world and events in our thinking contribute to making things
true. But he introduces a third kind of event, one critical to pragmatism:
agreement of ideas with what we already understand. Our prior stance,
he suggests, shapes both what we experience and what we think. This
stance is both intellectual and personal, rooted in who we are as indi-
viduals, with particular needs and goals.

An important consequence of this mode of thinking is the recogni-
tion that the method of obtaining data, of reasoning, and of setting
goals is bound up in what will be true in a given situation. The prag-
matists, therefore, opened the door for the recognition that what will
be true depends on the methods of truth setting. Rather than see this
as a hopeless circular argument, they leave it circular but embed it in
a relation between knowers and reality, where the outcome is not a
fixed truth but is a set of useful (i.e., pragmatic) truths.

The interpretation of truth and knowledge as derived from purpose-
ful reflection on experience and as anchored in utility has been signifi-
cantly updated by two recent movements. One is the development of
the epistemological consequences of the feminist movement to chal-
lenge the privileges associated with certain political, sociocultural, or
pedagogical structures (Brickhouse 2001). Feminist critiques of science
began with considering the reasons for the paucity of women in science, technology, engineering, and mathematics (STEM) fields but in the 1980s, led by thinkers such as Sandra Harding, advanced to other considerations. This included the role of sexism and other forms of bias in deciding what science is done, and the impact of sexist imagery on the methods of science in treating nature as an object to be mastered. However, the project also led feminist philosophers to raise questions of what it means to “know” in broad philosophical terms. Given the general feminist perspective that our actions, including acts of knowledge, are linked to our individuality, this epistemological perspective joined others that questioned the privilege of science as a method and as a body of knowledge. Harding and others sought a way to formulate a reliable perspective that replaced absolute systems. This led to the concept of feminist standpoint theories, summarized by Donna Haraway (1988):

We do not seek partiality for its own sake, but for the connections and unexpected openings situated knowledges make possible. The only way to find a large vision is to be somewhere in particular. The science question in feminism is not about objectivity as positioned rationality. Its images are … the joining of partial views and halting voices into a collective subject position that promises a vision of the means of ongoing finite embodiment, of living within limits and contradictions, i.e., of views from somewhere.

It is easy to take this goal of a “collective subject position” and to equate it with a single privileged position of knowing. As Harding (2004) argues, however, a key component of standpoint theory is that knowledge always comes from a set of “somewheres” that are constantly in flux and, in fact, are in relation with one another. This means that the goal of a collective position is not to find one place for knowledge but to find the one place that persons have assembled at a given time and place, understanding that this may or may not be the same place as that assembled by others in different times and places.

Taken together, we see that the philosophical anchoring of epistemology in experience, truth in the service of goals, and consensus in the conjoining of embodied views suggest that knowledge reflects the negotiation between the individual, society, and the world. This negotiation can result in several relationships, ranging from passive acceptance from authority, unstinting adherence to a particular perspective because it has worked in the past, and, finally, the active and open consideration of the meaning of past and current interactions with the world and with other persons as the basis of knowledge.
EXAMPLES OF AN EPISTEMOLOGY OF CONNECTION

The examples presented here represent, for the most part, programs that demonstrate a clear understanding that knowledge always has a component that connects the knowers individually and as a group to the knowledge that is taught. In the next section, we will consider psychological connections of the individual learner to knowledge, something that is different and much more common. Here, though, we seek cases where a curriculum or instructional system is clearly developed with an acknowledgment of the connection.

The opening example from the *Meno* raises the question of the status of Socratic instruction in chemistry. Often, Socratic teaching is reduced to various forms of teaching through questions (Chin 2007). However, there are also examples where the questions constitute a dialogue between an expert and a novice while they consider the evidence of a particular experience (which can be virtual, actual, or paper based). For example, in chemistry, Holme (1992) has reported on using spontaneous groups as the basis of Socratic questioning in lecture, but he also starts the session off with a simple shared experience, such as turning the lights on and off to form the basis of consideration of what occurs during the flow of electricity. DePierro et al. (2003) present a more detailed set of examples, with specific reference to student experience as a basis of discussion. Finally, Spencer and Lowe (2003) use a Socratic dialogue between an experienced teacher and a new teacher to discuss important questions of entropy, making particular use of the format as a way of exchanging information in a shared inquiry. This highlights that Socratic teaching can also be seen as the basis of guided inquiry instruction, now well represented by the Process Oriented Guided Inquiry Learning (POGIL) initiative that Spencer helped to found (Farrell et al. 1999; Spencer 1999).

Pragmatist philosophy, at least as formulated by James, Dewey, Peirce, and others, is essentially absent from chemistry instruction as an explicit viewpoint. Its cognitive connections are present, as discussed in the next section. But pragmatist views of knowledge are, I would argue, the basis of certain strands of constructivism, including that developed by Ernst van Glaserfeld (Tobin 2007), and were brought into chemistry education by George Bodner (1986; Bodner et al. 2001). Although he is also very clear that he adheres to the personal constructivism that is the basis of cognitive connections, Bodner does not shy away from following van Glaserfeld’s arguments, stating, for example, “From the perspective of the constructivist and radical constructivist theories, knowledge should no longer be judged in terms of whether it
is true or false, but in terms of whether it works. The only thing that matters is whether the knowledge we construct functions satisfactorily in the context in which it arises.” Bodner then relates this position to a variety of corollary ideas in teaching, including those specifically suggested from the work of Jean Piaget and George Kelly.

Bodner’s rich pedagogical work bears the mark of this philosophical stance, but there are few examples where the philosophical basis is presented plainly to students. One reason, we can infer, is that students may have to develop a more traditional view of a field before understanding the idea that the knowledge they are developing is itself always connected to the knowers who developed it. Working originally from Bodner’s perspective, Bhattacharyya (2008) studied the epistemic development of organic chemists through a cross-age study of undergraduate students, graduate students, and “seasoned” practitioners. Throughout, a functional approach to knowledge was found with the specific experiences of the learner, in the classroom and the research laboratory, shaping the conceptual development. Even the deep conceptual understanding of the seasoned practitioners was linked to the formation of a professional identity.

The feminist movement in philosophy is also matched well by ideas developed for a feminist pedagogy (Middlecamp and Subramaniam 1999). Part of this movement emphasizes the goal of giving students a voice in science, as discussed in the sociology of connection. But the direct consideration of epistemological considerations has been used also, when “Feminist classrooms explore the origins of ideas and theories, the position of those who put them forth, and the factors that influence how knowledge came to exist in its present forms.” Doing this in a thoroughgoing way is rare in chemistry education or in science education generally. Part of the reason is a tension inherent in teaching content for students to master while they also learn the situated origin of that knowledge (Richmond et al. 1998).

Finally, incorporating the history, philosophy, and sociology of science into chemistry curricula aligns instruction with Standard G of the National Science Education Standards, which includes the idea that science is a human endeavor (Rasmussen et al. 2008, but see also Erduran and Scerri 2002 and Scerri 2003 for other viewpoints). There is a risk that oversimplification leads to myth making as the details of history and sociology are trimmed to tell the direct chemical story. But there are also very good examples of specific and rich instruction, such as the story of the creation, use, and banning of chlorofluorocarbons. In this way, a variety of facts, including facts about chemical and physical properties, change the meaning of chlorofluorocarbons over time.
THE COGNITION OF CONNECTION

The second reason for considering connection as a basis of learning is its relation to the ways in which the mind works in itself. This brings in questions of cognition, ranging from questions of what we do with sensory information to how we interpret sense phenomena, consciously and unconsciously.

In this case, too, we have deep historical roots to contemporary ideas. The most prominent of these is in the writings of John Dewey. Dewey’s work can be classified into many different disciplines, including education, psychology, philosophy, and political science. Primarily, he was a theoretical thinker, but he always linked his work to practical problems, including those of democracy. He was a member of the pragmatist movement, linking with many of the ideas of James.

His emergence as a major thinker was solidified with the paper “The Reflex Arc Concept in Psychology” (Dewey 1896), where he criticizes the idea of analyzing psychological experiments in terms of “a patchwork of disjointed parts,” including sensation, ideas, and the nerve action that constitutes a response. Instead, he argued for analyzing stimulus, cognition, and action as a single whole, where sensation and reaction are coordinated, not sequential. A consequence of this is that sensation becomes deliberate, in response to and in anticipation of information from the outside world. Furthermore, what information comes in from the outside is constrained by prior experience, for prior experience provides the guide to interpreting that experience. Even in cases where sensations are instinctive, Dewey points, they are adaptive to the environment in which the organism typically exists. This creates a continuous circuit that, in Dewey’s analysis, is used repeatedly so long as it creates no problems. When problems occur—for example, when a child reaches for an interesting object to grasp it but finds a burn instead—refinement of the circuit occurs to include new ideas, new sensations, and new response acts. Throughout, it is experience that provides the basis for action, but it is thought (what he calls “psychic response”) that allows for reconstruction of a disrupted circuit.

Dewey moved his ideas quickly into questions of practice for education, including the work that he and his wife did in founding a laboratory school that focused on connections of thought with experience in the determination of action, as the basis of instruction. He recognized that this was quite radical, as he indicates in an address to the Psychological Society in 1900, where the heart of Deweyan psychology—experience, thought, and response existing in a circuit—therefore became a goal for pedagogy:
With the adult we unquestioningly assume that an attitude of personal inquiry, based upon the possession of a problem which interests and absorbs, is a necessary precondition of mental growth. With the child we assume that the precondition is rather the willing disposition which makes him ready to submit to any problem and material presented from without. Alertness is our ideal in one case; docility in the other. With one, we assume that power of attention develops in dealing with problems which make a personal appeal, and through personal responsibility for determining what is relevant. With the other we provide next to no opportunities for the evolution or problems out of immediate experience, and allow next to no free mental play for selecting, assorting and adapting the experiences and ideas that make for their solution.

Dewey, who was as much a political scientist and philosopher as he was a psychologist and educator, did little concrete work to link his assertions to experimental data of his own, even within the schools that he started or supported. Providing a psychological rationale (or theory) to explain why Dewey’s connected learning works fell to others. Important in this are Vygotsky, who worked on language acquisition, and Piaget, who introduced the idea of the role of personal knowledge structures that need to be deliberately challenged for learning to occur. Recent work has looked more carefully at the developmental psychology that explains why learning and doing science in context may be so effective. Throughout, a persistent theme is that the person, as the place where knowledge is constructed and maintained, will bring his or her own reasons to the knowledge.

The most recent scholarship in learning science through cognitive connective strategies has occurred in work on situated cognition (Brown et al. 1989). The idea of concepts as tools is central to the idea, leading to the idea of learning as cognitive apprenticeship. From this, several characteristics of situated learning emerge, as presented for the specific context of math learning (Brown et al. 1989):

- By beginning with a task embedded in a familiar activity, it (cognitive apprenticeship) shows the students the legitimacy of their implicit knowledge and its availability as scaffolding in apparently unfamiliar tasks.
- By pointing to different decompositions, it stresses that heuristics are not absolute but are assessed with respect to a particular task, and that even algorithms can be assessed in this way.
- By allowing students to generate their own solution paths, it helps make them conscious, creative members of the culture of problem-
solving mathematicians. And, in enculturating through this activity, they acquire some of the culture’s tools—a shared vocabulary and the means to discuss, reflect upon, evaluate, and validate community procedures in a collaborative process.

Of course, learning is often explicitly associated with apprenticeship to a trade or profession, and it is easy to design learning environments that fit the idea of apprenticing students for inclusion in chemistry. But the idea of connecting through cognition also has potential meeting in situations in which the student is not planning on being a chemist (or an engineer, or a doctor). There, the situation becomes a meaningful context for learning how new knowledge relates to the students in a potential, not in an actual, way.

The idea of situated cognition also relates to learning to use analogs of other domains. For example, anthropomorphic metaphors are introduced to provide students with a way of describing phenomena in psychological terms. Recently, the developmental psychologist Alison Gopnik has formulated the idea that cognition in science recapitulates the cognition that every child uses in learning. She emphasizes that every child has the challenge of learning about three things: language, other persons, and the world. And for all three, her evidence suggests, active theory formation and evaluation, accompanied by testing of theories through specific and intentional experiments, are the basis of how we learn how to talk, how to manage objects in the world, and how to work in an intensely social environment. While she underscores that science carries the study of “objects in the world” to another level while using the same cognitive skills, it is also important to recognize the importance of learning about “other minds” to the process of learning. If we are indeed skilled in figuring out, reacting to, and, if needed, manipulating, other minds, then the learning that connects content to human behavior may be effective. This can occur in two ways. First of all, since we are good at describing what other people do in terms of volition, ascribing volition to natural systems may make it easier to understand how they work, though of course, only in an analogical way. This is found prominently in anthropomorphic language and scenarios in learning. The second way in which our psychological impulse may be useful in learning may occur when we can connect learning to existing social systems. We make learning a component of working well in the social world, for example, through group learning and through role playing that allow us to bring our interest in working with and controlling people into how we learn chemistry.
EXAMPLES OF CONNECTION THROUGH COGNITION

It is probably a trivial statement to say that learning has to involve the cognition of the learner. However, in many cases, the curriculum or other aspects of instruction are passive in that regard, providing knowledge as a set of standard items to be acquired and used by students following a view of learning as a transmission process. Connections through cognition occurs when instruction explicitly uses the learner’s capacity to make a personal meaning part of the cognitive process. In this case, many examples are available in chemistry. Four different strategies are available:

- problem-based learning, including role modeling;
- inquiry learning;
- metacognitive strategies incorporating students’ thinking about themselves and their society; and
- use of analogies from other domains, including anthropomorphism.

I have already discussed how the first of these is present in chemistry education (Wink 2005) when instruction aims at making learning “relevant” to students. Problem-based learning fits well within the concept of situated cognition. Since problem-based learning requires students to use their knowledge to accomplish a task, it fits also in the category of “design” inquiry (Rudolph 2005). Design inquiry seeks to make knowledge connect to a goal that may lie outside the traditional curriculum, but it has the advantage of both bringing outside motivation (whether real or simulated) into the learning process, thereby connecting students with the “real” world. This can be carried out in limited ways in specific laboratories as in the general chemistry program Working with Chemistry (Wink et al. 2005), during unit-long exercises as in the high school Chemistry in the Community project (American Chemical Society [ACS] 2008), or over an extended period, as Gallagher-Bolos and Smithenry (2004) show in a year-long high school curriculum where students form a community simulating a soap company.

Inquiry, as Rudolph (2005) notes, is also something that occurs within a discipline and as students learn the content of the discipline. In this case, it fits more with definitions of inquiry that have students investigate concepts and processes within a subject, as suggested by Abraham (2005) and as used to assess curricula by Bretz, Towns, and
their coworkers (Fay et al. 2007; Buck et al. 2008). In that case, inquiry is primarily characterized by the extent to which the problem, the procedure, or both were developed by the student. The cognitive connection here is found when the student must generate important elements of the experiment, presumably through thinking that connects with the students’ prior knowledge and plans for the experiment.

Metacognition, where students are aware of and regulate their thinking as part of the learning process, is a recent addition to the chemistry education toolkit. Rickey and Stacy (2000) discuss different examples of this, including the specific example of having students discuss their work to share and critique their ideas in a common project. In chemistry, strategies include paper- and computer-based procedures to document students’ conceptual reasoning through tools such as thinking frames (Mattox et al. 2006), concept maps (Francisco et al. 2002), cooperative groups (Cooper et al. 2008a), and work in using extended writing within laboratory work (Greenbowe and Hand 2005). Recently, Cooper and coworkers (2008a,b) have studied this to uncover to what extent a students’ metacognition affects complex problem solving and, more importantly, how instruction with metacognition can prompt some learners to shift their problem-solving strategies from less to more productive modes.

Perhaps the most general way in which metacognition can be used to connect students to the learning of chemistry is through writing that includes a deliberate reflective component. This has been well documented in science and in chemistry through work on the science writing heuristic (SWH) (Hand 2007), part of the general idea of writing to learn in science (Wallace et al. 2007). Such strategies undoubtedly aid in students’ learning to understand and to use the complex vocabulary of science (Wellington and Osborne 2001). Writing is also a means to support knowledge growth (Keys 1999). The SWH allows students to connect through the acts of developing beginning questions, designing and executing a data collection plan to answer the question, developing claims based on evidence, and reflecting on their experience and its relation to knowledge. As a result, when implemented well, the SWH benefits learning of basic chemical concepts, including, for example, thermochemistry (Rudd et al. 2001). At several different points, students have to formulate their own responses, from the initial questions to the final reflection, providing strong connections between thinking and activity.

The cognitive connections available through analogies are much more widespread in part because analogies are probably a basic cognitive skill themselves. Orgill and Bodner (2005) discuss that analogies
allow instructors to support student growth in a new domain (like biochemistry) through connections to prior knowledge in a familiar domain. Scores of articles have been published on the use of analogies. Some reflect the fundamental analogies used to describe chemical and physical systems at the atomic–molecular scale using macroscopic analogies, such as standing waves (Davis 2007). Others provide students with graphic or analogical organizers for their problem solving (Ault 2006). Also, the use of any macroscopic model is an example of analogy (Justi and Gilbert 2002). Many introduce human sensory constructs into the analysis of the actions of molecules (e.g., sight: Mattice 2008). Problems arise, however, when students either do not appreciate the analogy because they do not understand the analog domain or, in other cases, elements from the analog domain can transfer into the target domain, causing confusion and misconceptions.

Perhaps the most interesting kind of analog connection is in ascribing psychological states to atoms and molecules. This is embedded in the basic classificatory schemes of chemistry, as in the concepts of hydrophilicity (“loving water”) and hydrophobicity (“fearing water”) in describing the interactions of substances with water. Such psychologizing and the associated anthropomorphic language permits instructors to take on the wide range of experience that the students have with people and to use it in the classroom, perhaps exploiting a basic human cognitive function in solving the problem of “other minds,” which is so vital for a social animal (Gopnik). Certainly explicit anthropomorphism is widespread in chemistry education, beautifully illustrated by the work of Primo Levi in The Periodic Table, where the analogy between a person or a group and an element is used as the driver for his writing. Having students create their own analogies is a form of metacognition, but also runs the risk of stereotyping “people as well as molecules” in dangerous ways (Miller 1992). In addition, carrying things too far with any analogy occurs in anthropomorphism also (Taber and Watts 1996). Certainly, this is the case when the analogies move into the area of sexual attraction, both explicitly and implicitly (Biology and Gender Study Group 1989), that describes chemical reactions between small energetic nucleophiles and large, passive substrates in violent terms of attack.

THE SOCIOLOGY OF CONNECTION

Our last perspective comes from considering the relationship of connections between scientific knowledge and learning on the one hand and
society on the other. This is a reciprocal relationship, where we consider how what is known in science and how science is taught both affect society and, conversely, how society affects what is known in science and how science is taught. As with epistemology and cognition, the role of sociology in science is generally acknowledged by all at a trivial level: It is true that humans in society carry out science, teach science, and learn science. Hence, science always has a human element, but traditional views of science probably emphasize that science itself ultimately transcends these social elements (Haack 1996) and that learning ultimately is about participating in a set body of knowledge, not participating in its construction (Matthews 1994; Scerri 2003).

Instrumentalist views of science challenge strongly these views of the subject. Steve Fuller, a sociologist and philosopher, has, for example, cast these differences in the form of a contrast between “disenchanted science” and “enchanted science,” contrasted in Table 1.1 below.

The consequence of the first kind of science, he argues, is a public one and the alienation of students from science because, in almost all areas of life, knowledge has moral, value, and political components. In this case, therefore, learning that connects with these kinds of “enchantment” is likely to be considered more legitimate because it invites the learner to consider how participation in science extends from his or her normal activities in society. Furthermore, Fuller elsewhere emphasizes that science has a “governance” structure that reflects those who will use (or abuse) science. He sees significant problems that occur when we avoid this governance structure, which arises when science becomes a special subject. Instead, Fuller argues for embracing the structure and for acknowledging the sociological facts that all science reflects society, including the society of those who are attempting to learn it.

Fuller and others in the science studies movement such as Bruno Latour (1999) and Helen Longino (2002) are primarily analytic in his approach, working to develop and to interpret evidence of the enduring connection science content and learning to society. Another thread in

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<td>Disenchanted Science</td>
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<td>... is a value-neutral mode of inquiry.</td>
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the sociology of connection considers the issue of participation (or nonparticipation) of different groups in science. This reflects pedagogical questions raised by thinkers like Paolo Friere and bell hooks, who argue for teaching that specifically targets the problems of those who are not participants as the basis of what Friere, in one of his most famous texts, calls the “pedagogy of the oppressed.” In this case, the solution to a science that excludes, or seems to exclude, other groups is to take those lives and to make them the basis of science and science learning. This is both a correction to the distortion of the current system and a way to bring other groups into learning.

A particularly effective discussion of this in the context of learning science was presented by Maralee Mayberry (1996), also a sociologist, in her analysis of “reproductive and resistant pedagogies.” In analyzing conventional views of collaborative learning, she finds that it “engages students in an ongoing conversation about these aspects of disciplinary knowledge, and in turn trains students who are capable of adapting to the ‘conventions of conversation’ in educated communities.” This, though, occurs within a sociological framework of bringing students into the viewpoints of the unchallenged community that exists before learning. Hence, she sees reproductive pedagogy as maintaining the sociological relationships of insider and outsider. In contrast, she sees that “the feminist classroom conversation and process of knowledge production are overtly political and aimed toward social and educational change,” that if we want to have a change in science to make it more responsive to social needs, we need to bring in both a critique and a participation scheme to allow students to raise questions about what goes on now.

**EXAMPLES OF CONNECTION THROUGH SOCIOLOGY**

Connections through sociology can occur in three different ways. These follow a schema suggested by Capobianco (2007), working from a perspective of feminist pedagogy. One examines the classroom as a place where inclusion needs to be fostered by bringing new audiences to the learning of science. The second way for a connection through sociology addresses changes in the categories of a field so that the field itself encompasses more areas of inquiry, including other groups that have been traditionally excluded. The third looks at the actual practices of a field and attempts to engage in “transformative practices.” These are similar to a schema used to survey the literature on girls and science (Brotman and Moore 2008).
Inclusion of more groups in a field can be as simple as providing instruction specifically to those who are not usually taught a field. This is present, for example, in many different programs that target a group or groups for teaching and is the basis of programs for girls and women (e.g., Jayaratne et al. 2003; Brotman and Moore 2008). In this case, the step of bringing a target population into contact with science is supposed to have an effect of enhancing understanding and of increasing interest. In some cases, specific content that may be relevant to the target population is included, for example, in the Summer Science for Girls program that provided eighth-grade girls with hands-on instruction in science while also exposing the participants to women scientists as role models and providing “exercises aimed at dispelling the stereotypes associated with women doing science.” Such a combination of content and motivational work was also present in a chemistry-based outreach program from Simmons College (Lee and Schreiber 1999).

Targeted interventions as a means for connecting chemistry to new groups are also present implicitly in many programs that work with the educational venues where many students take chemistry. Prominent among these are efforts to affect chemistry instruction at community colleges, the site of the majority of undergraduate general chemistry courses. This is prominent as a driving force behind the recent work of the National Science Foundation Division of Undergraduate Education, which has allowed for expanded funding of Course, Curriculum, and Laboratory Improvement projects that include community college participation. Perhaps more important is the concept that community colleges are themselves a source of valuable insight into how to include more students in chemistry learning, for in those environments, instruction is much more likely to be responsive to the particular sociological makeup of a population, as recently highlighted by the ACS in a discussion of Hispanic-serving institutions (ACS 2008). The impact of such inclusionary practices as the ACS Scholars and Project Seed programs is good evidence that connection by simply exposing more students to chemistry, especially research chemistry, is in itself an effective means for increasing participation.

Although inclusion is a necessary step in connecting more students to chemistry, there is also good reason to suspect that additional steps are needed. Thus, the second way in which a connection through sociology can occur is by incorporating specific discussions of race, ethnicity, and gender within instruction. The theoretical and methodological components of such cross-cultural instruction, including implications for research and practice on student connections, have been explored
by Aikenhead and Jegede (1999), where they examined the ways in which instruction involves “cultural border crossing” that may either exclude or include students. In this case, factors such as students’ home lives, the ability to “play in the new environment,” and resistance as “science teaching ... attempt[s] to assimilate them” all affect student movement into science.

An alternative to assimilation is to make clear to students that they may cross the sociological border into science with their cultural identity both intact and, perhaps, valued. This is a specific goal of the work of Middlecamp and Subramaniam (1999). Within the biological sciences, including gender as a specific component of course content is a more obvious move than in chemistry (Birke 2001). There are more studies in which a connection of chemistry to sociology occurs through the lens of race and ethnicity, for example, in the Project Inclusion work of Hayes and Perez (1997) and the multicultural examples developed by Middlecamp and Fernandez (1999).

The third way in which connection on the basis of sociology can develop is when educators and students engage in learning that has the potential to change the way in which science works in itself. As noted earlier, such a transformation is easier to contemplate and perhaps to accomplish in areas where social interactions seem to be more prominent, for example in biology. Considerably less is known about how science might change if, for example, women’s voices were more prominent. At the very least, the relationship of the history of the physical sciences and military goals has been well documented (Schiebinger 1999; Fuller 2002; Rudolph 2002). But the specific case of chemistry—whether chemistry as traditionally taught reflects the perspectives of a limited sociological group—is not well studied. Some work, noted earlier, examined how images of chemical reactions as a site for a passive (i.e., feminine) receptor molecule undergoing attack by an energetic nucleophile may reflect a gendered history within the description and understanding of chemical reactions (Biology and Gender Study Group 1989).

Little is known about how chemistry might change if the influence of other sociological groups (women, persons of color, non-Western cultures) were given more control. An exception is present in the work of Aikenhead and Ogawa (2007). They documented how three different world views (North American indigenous, Japanese, and Euro-American) approach not only knowledge but also what is known. In particular, they recognize a fundamental difference between the views that science is a distinct way of knowing (in Euro-American traditions) compared to efforts to make science a part of traditional knowledge
cultures. The emergence of “ethnoscience” within environmental science and biology exemplifies that specific knowledge and ways of thinking from traditional groups may indeed influence how the world is viewed (Snively and Corsiglia 2000).

These previous studies, because they are based outside of chemistry, do not address the question of how chemistry itself might be transformed if standpoints other than those of white males were included as a fundamental part of chemistry knowledge. This does not mean that connecting different social groups to the production of knowledge will not change knowledge; rather, it is a suggestion that this is an area that still needs to be researched, probably in conjunction with teaching of nontraditional groups. One set of perspectives on how this may occur comes as a consequence of Sandra Harding’s (2001) discussion of why feminist standpoint epistemology suggests new directions for science. Among her “‘grounds’ for the feminist claims” are the following:

- The neglect of women’s lives as starting points for research implies that including these may lead to new avenues of research.
- Considering the “strangeness” of women to the social order in science prompts researchers to view the dominant viewpoints as possibly defective while the traditional oppression experienced by women means they have an interest in keeping a focus on examining the basis of knowledge. Together, these mean that women’s standpoints are the right starting point to examine whether the traditional knowledge is valid.
- Women have played a very large role in the production of “craft” knowledge over time. Considering craft knowledge as a starting point for science has the potential to create new descriptions and rationales for science, and therefore perhaps new kinds of science.

These points can easily be changed to include other nontraditional social groups and, as noted, there are examples of connecting the learning of chemistry to the lives of other cultures. But these are few, and new ideas and research in this area is necessary before the questions of “what would a nontraditional chemistry look like?” can be answered.

REFERENCES


