MAKING CHEMISTRY RELEVANT

STRATEGIES FOR INCLUDING ALL STUDENTS IN A LEARNER-SENSITIVE CLASSROOM ENVIRONMENT

Edited by

Sharmistha Basu-Dutt
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Learning is a complex and multifaceted process that can be facilitated in a classroom environment that is challenging, yet flexible, allowing students to find meaningful relationships between abstract ideas and practical applications in the context of the real world. Creating inclusive learning environments that connect to a diverse student population opens doors of opportunity for students throughout their lives. Students’ interest and achievement in academics improve dramatically when they make connections between what they are learning and the potential uses of that knowledge in the workplace and/or in the world at large. This book presents a unique collection of strategies that have been used successfully in chemistry classrooms to create a learner-sensitive environment that enhances academic achievement and the social competence of students.

In Chapter 1, Donald Wink 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 main philosophical point is that knowledge is stronger when it is based on connections between the learners and the material. Rationales for connected teaching in chemistry also arise from understandings of cognition, specifically by considering how they construct meaning within their own thinking. And sociological issues arise when considering how to connect the learner to chemistry because of goals of inclusion and diversity in the enterprise of teaching chemistry.

Chapter 2 introduces the ideals of Science Education for New Civic Engagement and Responsibilities (SENCER), a national dissemination project supported by the National Science Foundation and the National Center for Science and Civic Engagement, focusing on connecting basic chemical principles to complex, public issues through campus- and community-based research projects as well as course content and structure. Amy Shachter describes a SENCER model course that uses students’ active participation in civic engagement as a means of learning science.

The Center for Occupational Research and Development (CORD), a national nonprofit organization, provides innovative changes in edu-
cation to prepare students for greater success in careers and in higher education. In Chapter 3, Mark Whitney and Bonnie Rinard elaborate a laboratory-centered, hands-on activities-based CORD module that emphasizes the importance of teaching science in the context of major life issues surrounding work, home, society, and environment.

Combating terrorism and preserving our environment are two critical issues that are of national and global interest today. Laura Eisen presents an interdisciplinary course on the science of terrorism in Chapter 4. The course is intended to increase the scientific literacy of nonscience majors who will use this knowledge to make sociological, economic, or political decisions related to homeland security in their future careers. In Chapter 5, Gautam Bhattacharya shows how Green Chemistry has taken the center stage in the new millennium as the sustainability of the human race has become the most important scientific, economic, social, and political challenge in the world. Examples presented help students understand that, when used in an environmentally and ecologically conscientious manner, chemicals and chemistry produce many of the staples of human existence.

In Chapter 6, Gail Marshall discusses some general features of a variety of commonly used student-centered, active learning pedagogies in science education. Laura DeLong Frost focuses on reorganizing the content in allied health chemistry, making it more interesting to students and the incorporation of the process-oriented guided inquiry learning (POGIL) approach in Chapter 7.

The development and implementation of the Working with Chemistry (WWC) Laboratory Program is highlighted by Julie Ellefson in Chapter 8. Specific WWC modules that contain sets of experiments linked by a scenario describe a situation/problem that a professional who uses chemistry regularly but is not a chemist may encounter in the context of his or her work.

In Chapter 9, a team of interdisciplinary faculty comprising Julie Bartley, Sharmistha Basu-Dutt, Victoria Geisler, Farooq Khan, and S. Swamy-Mruthinti, describe three freshmen seminars to introduce students to the contextual relevance of introductory science and mathematics courses, providing a “keystone” experience that enables them to engage in science and mathematics within the context of their professional goals. The seminars provide an intellectually exciting experience for entering science, technology, engineering, and mathematics (STEM) students using active learning methods, multidisciplinary experiences, and skill development in the context of real-life problems.

Cianán Russell, Anne Bentley, Donald Wink, and Gabriela Weaver describe selected modules from The Center for Authentic Science
Practice in Education (CASPiE) program in Chapter 10. These modules provide first- and second-year students with access to research experiences as part of the mainstream general and organic chemistry curriculum; create a collaborative “research group” environment for students in the laboratory; provide access to advanced instrumentation for all members of the collaborative to be used for undergraduate research experiences; and create a research experience that is engaging for women and for ethnic minorities and appropriate for use at various types of institutions, including those with diverse populations.

In Chapter 11, Maria Oliver-Hoyo introduces a variety of unique multisensory experiments that are designed to use other senses in addition to eyesight when studying chemical processes and performing chemical techniques. Besides adding richness to the chemistry experience of all students, these sensorial experiments provide an opportunity to integrate visually impaired students into the laboratory experience in an active and independent manner.

Entertainment and variety are universally sought human experiences, the thirst for which can be exploited in the classroom, with the help of hypermedia. In Chapter 12, William Donovan illustrates the use of interactive websites and response systems to increase their understanding of chemistry concepts alone and in collaboration with other students, tutors, and teaching assistants (TAs), and their instructor. Erik Epp and Gabriela Weaver present the development and use of a Physical Chemistry in Practice DVD in Chapter 13 that combines video, audio, and graphical and textual information in an interface. With the help of hypermedia, students can choose the order and pace of accessing information, giving them great flexibility and allowing them to work in the way that they learn best. Successful puzzles and games in the context of learning utility are demonstrated by Thomas Crute in Chapter 14.

This book is a synthesis of work by many passionate faculty members who possess similar goals of creating an inclusive classroom environment for their students. We hope that novice and experienced faculty will find valuable ideas in this book and be able to adapt these or to develop their own strategies to enhance the learning experience of all their students. We welcome your comments and suggestions for improving this book.

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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


*Making Chemistry Relevant: Strategies for Including All Students in A Learner-Sensitive Classroom Environment*, Edited by Sharmistha Basu-Dutt Copyright © 2010 John Wiley & Sons, Inc.
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

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 lectures that William James gave on the subject. In these lectures, he makes clear that truth is rooted in how the knower sees a given proposition 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 relations 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 individuals, with particular needs and goals.

An important consequence of this mode of thinking is the recognition 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 pragmatists, 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 purposeful reflection on experience and as anchored in utility has been significantly updated by two recent movements. One is the development of the epistemological consequences of the feminist movement to challenge 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 occur 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