University faculty who teach required science courses for prospective teachers generally use traditional approaches to teaching in which learning is conceptualized in terms of a transmission model. Thus, prospective teachers learn science in learning environments that encourage memorization of science information and that place relatively little emphasis on understanding knowledge and how to use it in daily life. It is not surprising, therefore, that many new teachers of science create learning environments in their own classes that are very similar to the environments they experienced as students of science.

More than 400 national reports (Hurd, 1994) published in the United States during the 1980s and 1990s (e.g., National Research Council, 1996; National Science Teachers Association, 1992; Rutherford & Ahlgren, 1990) have called for reform in science teaching and learning, particularly in classes for prospective teachers. Shortcomings of science education have been traced back to the elementary school level; so the preparation of prospective elementary school teachers to teach science is a major concern. These national reports call for major changes in what, when, and how we teach science, many recommending more constructivist teaching approaches (Glaserfeld, 1989) in science classes for prospective elementary school teachers. There is a prevailing view that prospective teachers need to experience learning environments in which meaningful learning takes place.
A recent study of exemplary science teachers has linked success at improving student interest in science with providing a context in which meaningful learning can take place. Such teachers, as noted by Collette & Chiappetta (1994), modify “the context within which the subject matter is taught so that it connects with what students know and is perceived to be relevant, yet in a manner that relates to the curriculum” (p. 76). They endeavor to make their teaching appealing by creating an environment that is rich in interesting activities and topics. Such an environment motivates students to be actively involved in the learning process, using prior experience and knowledge to construct meanings in new situations.

This chapter draws on the results of a study designed to examine the classroom actions of an exemplary university chemistry teacher of prospective elementary school teachers and the way that actions relate to his beliefs, goals, and teaching roles. The central purpose of the study is to understand the metaphors that Mark (a pseudonym) uses as referents to conceptualize his roles and frame his actions and interactions and, thereby, to generate an exciting environment for learning. We use pseudonyms for the students throughout the chapter to protect the anonymity of the participants.

The significance of this case study concerns the ways in which a university chemistry teacher and his students conceptualize their own roles and those of others in the class, and how the teacher’s varying roles mediate the construction and maintenance of an environment that encourages and stimulates students to learn science actively.

Roles of the Authors

Abdullah Abbas conducted his doctoral dissertation research on Mark’s teaching (Abbas, 1997). Abdullah was particularly interested in studying Mark because he wanted to improve his own teaching in his native country of Yemen, where he is a professor of science education. Abdullah chose to study Mark’s teaching because Mark was an exemplary teacher, as evidenced in prior studies by Brush (1993) and Duffy (1993).

The second author, Kenneth Goldsby, is Mark, the teacher whom Abdullah studied. We chose a pseudonym so Ken himself does not get fixed in time as he was during the study. Ken was involved formatively throughout the study, and also served as the “outside” representative on
Abdullah’s College of Education dissertation committee. While Mark is frozen in time, Ken continues to learn, develop, and evolve in his beliefs and philosophy on the practice of teaching.

The third author, Penny J. Gilmer, was one of two principal investigators with Ken Tobin for the National Science Foundation grant that supported the development of this course. Penny was active in working with teams of scientists, K-12 teachers, and science educators to develop three new interdisciplinary science courses, including the physical science course described here, designed for prospective elementary school teachers. She also was Abdullah’s major professor.

**An Interpretive Research Approach**

We employed an interpretive research design, described by Erickson (1986) and Guba & Lincoln (1989), in the study. Erickson (1986) defines interpretive research as “the immediate and local meanings of actions, as defined from the [participants’] points of view” (p. 119). The basic assumption of this type of research is that the researcher and her or his subjective experience provide the lens through which the research develops (Brush, 1993). The main sources of data for this study are field notes, transcript analysis of interviews with the teacher and students, and analyses of videotaped excerpts. We employ additional data sources to ensure that the inferences we constructed are consistent with the variety of data.

Constructivism (Glasersfeld, 1989) and co-participation (Lemke, 1995; Schön, 1985) are the main theoretical frameworks of the study. The basic tenet of constructivism is that knowledge is personally constructed but socially mediated (Tobin & Tippins, 1993). Knowledge is always the result of constructive activity by an individual while he or she exists in a cultural sense. This epistemology enables us to make sense of how students learn and how the teacher works with them to create learning environments that enhance their learning.

Within a constructivist framework, participants become empowered and act and reflect on their actions. Through interaction with others, the students can negotiate meanings of actions to arrive at a consensus on what has been learned. Co-participation implies, as stated by Tobin (1997), “the presence of a shared language that can be accessed by all participants to communicate with one another such that meaningful learning occurs” (p. 369). The teachers who know science assist students
to learn by engaging in activities in which co-participation occurs (Roth, 1995). In such situations, students are empowered to engage actively in the process of knowledge construction and have the autonomy to ask questions when they have problems (Tobin, 1997).

An interpretive approach to studying science teaching and learning, as suggested by Guba & Lincoln (1989), requires that the study takes place in the natural location or place, such as a classroom or a laboratory, where the events occur that we wish to interpret. We conducted this study in a university physical science course designed especially for prospective elementary school teachers. Our focus is on the actions of Mark, the chemistry teacher. His reading and reflection on the audiotape and videotaped transcriptions provide what Guba & Lincoln (1989) refer to as “member checks.” The researcher’s prolonged and intensive engagement (Guba & Lincoln, 1989) in the class during the whole semester added to the credibility of the study.

The following vignette is a reflection on the class taught by Mark in which he utilizes dry ice and liquid nitrogen in a class activity. It is based on field notes, an analysis of the videotape and interviews, and a review of students’ journals. The vignette provides insights into the learning environment that Mark endeavored to create in order to maximize students’ participation in science learning.

**Smashing Up the Ball Against the Wall**

*Caught Me off Guard*

It was Friday. Students and teachers were wearing heavy clothes because it was very cold. Two teachers and the two teaching assistants, Chris and me, plus twenty-one students, all females, were in the class. Students were arranged in five groups, each group with four or five students. The physics teacher, Adams, finished his presentation about error in measurement at about noon.

The chemistry professor, Mark, began talking about temperature and explained the connection between temperature and the concepts of density, volume, and mass, which were explained by Adams in the first hour of the class. Then he gave a short presentation, for approximately fifteen minutes, about temperature, Fahrenheit scale, Celsius scale, Kelvin scale, and the boiling and freezing points of water in each scale. He used the chalkboard to draw three thermometers representing Celsius (°C), Fahrenheit (°F) and Kelvin (K). For each scale the students were
shown both the boiling and freezing points of water.

At about 12:15 P.M., Mark asked the students to start activities with liquid nitrogen and dry ice (solid carbon dioxide). He clarified to the students how liquid nitrogen and dry ice are very cold, their temperatures being 189.8°C (-320°F) and -87.8°C (-109°F), respectively. Then he poured some liquid nitrogen into his hand, but it turned to gas as quickly as it reached his hand. He explained to them how this demonstration indicates that the hand temperature is very high compared to the temperature of the liquid nitrogen. The students became excited after this demonstration. When he showed them the dry ice, they were enthusiastic to see how these small pellets turn from a solid phase to carbon dioxide gas without getting their hands or the table wet. Mark described the different uses of dry ice in our daily lives, such as keeping drugs or foods refrigerated when they are sent by mail.

After a short break, students came back to the class eager to start their activities. Before starting, Mark showed them how the volume of nitrogen gas can be measured by putting an amount of liquid nitrogen into a test tube, then immediately putting a balloon over the top of the test tube. The balloon began to inflate due to the liquid becoming a gas. Then Mark asked them to start group work and write down their observations and comments about what they observed. He gave each group some liquid nitrogen in a Styrofoam cup while the teaching assistant distributed balloons and some dry ice to each of the groups. Each student worked in her group to perform the activity.

On the first occasion when balloons were being immersed in the liquid nitrogen, some students moved away and put their hands over their ears. They expected the balloons to burst. Students showed their excitement as they worked, especially when Mark, who previously had immersed a racquetball in liquid nitrogen, threw it against the wall and it shattered into many pieces. Some students searched the floor looking for pieces of the ball. One student, Nora, commented on these actions in an interview as:

That was neat. I liked playing with that. That was fun, to see [the ball] smash up against the wall, and the balloons with the air, and then the dry ice that we used and just threw on the table. I like doing crazy things like that. I didn’t expect him to throw the ball up against the wall. That caught me off guard.

Aisha wrote in her journal the following description of what her
We experimented with small pellets of dry ice. We stuck one pellet of dry ice in the balloon and tied it up. The dry ice begins to blow the balloon up slowly and then eventually almost appears to stop until we pick it back up and shake it and bring the inside to motion. We also did some experiments with the liquid nitrogen. [Mark] stuck a racquetball into the liquid nitrogen and it immediately turned into a glass-like state. [He] then threw the ball against the wall and it shattered into many pieces. We stuck our balloons with the dry ice in it into our cup filled with liquid nitrogen. The balloon seemed to collapse and [shriveled] up when coming in contact with the nitrogen.

While work in the activity continued, students discussed with each other within groups what they observed and sought help from Mark when they needed assistance. Mark moved from one group to another to assist students with their work, participate in discussion, and help them to understand what to do.

One student asked a good question, “What will happen if we blow a balloon up using regular air and put it into the liquid nitrogen?” Mark asked each student to predict and discuss within each group what would happen in this example, and to record their predictions before putting balloons with air into the liquid nitrogen. When they finished recording their predictions they inflated their balloons with air. Aisha wrote in her journal about her predictions and observations as follows:

My prediction about blowing the balloon up with regular air instead of using the gas given off from dry ice is that it will burst under the pressure of the density of air inside the regular balloon. My guess is that it will pop. The air balloon shriveled quickly after being immersed into the liquid nitrogen then went back to its normal state as it was before being blown up. Then, we tried the dry ice once again and it seemed to drip condensation.

After a while they were asked to look for whatever they could see inside the balloons filled with air, such as liquid, after putting them in the liquid nitrogen. The teachers tried to help students to observe liquid inside the balloons. Some students could see a liquid, while some of them could not. Huda, for example, wrote in her journal, “I saw a liquid in the balloon for a second, but then it disappeared as the balloon got its shape back. I have no idea what it is.” But Aisha wrote in her journal,
“Although we were asked to see something inside of the air-filled balloon many times, I never really saw anything worth noting. Nothing was inside of the balloon.” Before ending the class, students within each group discussed their observations and wrote what they thought in their journals.

**Teaching for Active Learning**

Beliefs about how students learn science can have a direct influence on the classroom roles of science teachers (Tobin, 1990a). A belief, as noted by Tobin & LaMaster (1995), is “knowledge that is viable in that it enables an individual to meet [his or] her goals in specific circumstances” (p. 226). When a science teacher has a belief that students learn science by listening to his or her lectures, for example, this teacher tends to use a transmission-absorption model for teaching and learning. Within this model, students pay less attention to meaningful learning since the teacher’s goal is to cover the syllabus of the course and prepare students to pass the tests.

However, Mark’s approach to teaching science is dynamic. He encourages students to engage actively in discussions and activities intended to promote their interest in chemistry learning. This approach is consistent with his goals of creating learner-centered classrooms and maximizing the participation of his students who are non-science majors and frequently have negative feelings about science (Brush, 1993). Using different strategies for teaching indicates that Mark is always on the lookout for ways to stimulate active and varied student participation. Chemistry classes are rich with exciting demonstrations and hands-on activities, such as the dry ice, liquid nitrogen, and balloons described in the vignette, which Mark selects to stimulate students’ active engagement in the learning process.

In an interview, Mark emphasizes his beliefs about the importance of active learning in class of prospective teachers:

> I understand the constructivist’s view that we cannot transfer knowledge intact to our students, but initially I thought that I could at least transfer my enthusiasm about science intact to someone else. I know now that I cannot do that, or at least I can only do it for a little while. The students have to construct their own interests. My role is to facilitate that process. I have to help the student find some reason that this material is interesting.
or relevant. I can’t transfer my interest or my sense of relevance to other students. They have to construct that for themselves.

Underlying Mark’s beliefs about learners who are actively involved in science learning is a set of beliefs about the nature of learning and knowledge that he referred to as constructivism. As a referent for teaching, constructivism can shape the direction of a teacher’s actions and his role as a science teacher in the classroom. Mark believes that to have students learn science actively means to create an environment in which alternative ways of teaching and learning can facilitate students’ learning processes. If we consider learning from a social constructivist perspective, learners are no longer passive agents, but they engage in interactive discussions or in small group problem-solving activities. Accordingly, the teacher’s role changes from a giver of knowledge to a mediator of learning (Tobin & Tippins, 1993). The science teacher, as Tobin and Tippins (1993) note, “takes account of what the students know, maximizes social interactions between learners such that they can negotiate meaning, and provides a variety of sensory experiences from which learning is built” (p. 10).

Mark’s main goal is to maximize the participation of his students. He is always looking for ways to stimulate active and varied ways of participation among them. His classroom actions aim to stimulate students to participate and learn actively through doing science in which they can construct their own understandings of science concepts. It is clear that he works hard in chemistry classes to move from teacher-centered to learner-centered approaches of teaching and learning where alternative ways of science teaching and learning could be utilized. These findings are consistent with those of two studies conducted in the past few years about this course (Brush, 1993; Duffy, 1993).

It seems that Mark’s beliefs about science teaching and learning evolved during his work as a science faculty member and a college science teacher. He comments on how his beliefs about science teaching and learning evolved during his work as a college science teacher in the following way:

I had heard a great deal about constructivism before beginning these courses. I think we all know that you learn by doing. Show me something and I’ll remember it for a minute; let me do it and I’ll remember forever. So I thought constructivism was just another way of saying that the best way to learn something was to do it. That is why I wanted to get on board
[in this project] because I knew that is true from my own experience with
laboratory research. The best teaching we do, the best learning
environment we create for students, is when we bring them into our
laboratory and have them do science in a mentoring relationship.

To achieve the goal of setting up exciting environments for
learning in the classroom, Mark used metaphors to conceptualize his
roles in creating such environments. Mark was able to switch his actions
based on which of the constituent metaphors he used as a referent to
frame his actions and interactions, and thereby, to create an exciting
environment for learning.

“Learning is an Exciting Trip”

An assumption underlying this study is that many of Mark’s beliefs
about teaching and learning are metaphorical. We propose that, as Mark
reflects on his actions and considers the various roles that he might
adopt, he makes sense of his roles by the use of metaphors. Mark’s
personal epistemology is considered relevant in deciding whether or not
a particular role is appropriate for use in his science teaching. If the role
is consistent with his beliefs, the decision might be to adopt the role but,
if not, the role might be considered inappropriate (Tobin, 1990b). Data in
the study suggest that actions in Mark’s classroom are metaphorical and
consistent with his belief that students can learn science meaningfully
when they enjoy the learning process.

Teaching practices in Mark’s classes for the last few years (Duffy,
1993; Brush, 1993) indicate that Mark, as a constructivist teacher,
developed his own metaphor to serve as a referent for his teaching
practices. It is clear that his actions are embedded in the metaphor that
“learning is an exciting trip.” Mark used his beliefs, which are associated
with constructivism, as a referent for actions in his classes and for the
metaphors in which he embedded his actions. To be consistent with his
beliefs that students should enjoy while learning science meaningfully,
Mark uses the “trip” metaphor to construct a vision of what science
classes for prospective teachers could be like. Such a metaphor is evident
in interviews and in actions and interactions in Mark’s classroom.

Mark describes actions and interactions in his classroom in terms
of this “trip” metaphor, in which he conceptualizes his role as the trip
driver, or a tour guide, and students’ role as the travelers. In an interview,
Mark describes the way in which he uses the metaphor of a trip to justify his approach in teaching and learning:

Learning is like a trip, and the teacher is the driver. [The driver points to a building] “And this is the Capitol and it was built in 1856…Let’s go over here, I want to show you the legislative building, two bodies.”…The students are in the back saying, “What is that building?” You go, “That’s a neat building, do you want to go see it?” Or, “That building is not very interesting. Do you really want to go there? Maybe we can come back to it if we have time.” This is a quickly thrown together metaphor for what I think the teacher should be doing. The first time I taught the chemistry course [an early version of the physical science course] I thought I should empower the student. I thought, “It’s their course…I’ll let them drive. I’ll let them decide where we go.” Sounds great in theory, but it did not work very well. Students are not used to being empowered. They don’t know where to go or how to get there.

Underlying the trip metaphor is a more constructivist epistemology in which every person, including the driver, is involved actively in the trip and associated activities. Another important referent used by Mark is enjoyment. He believes that learning chemistry, especially for elementary education majors, should be enjoyable. The driver endeavors to create a high-quality atmosphere in which travelers enjoy learning about things and places along the way in their trip. This is consistent with Mark’s actions in classes for prospective teachers (Duffy, 1993; Brush, 1993) to create exciting environments of learning through the use of different demonstrations and learning activities.

In a similar study, Ritchie (1994) described how a teacher used a metaphor of “teacher as travel agent” to transform her teaching to better agree with constructivism. This teacher used the metaphor as a referent for actions in her classroom. After a period of time, the teacher taught in a more routine manner and was less reliant on using the metaphor to guide her teaching practices. Using the trip metaphor allows Mark to focus on facilitating student learning through the use of instructional strategies to maximize the participation of all students in learning activities.

The trip driver enjoys the trip when he feels that other participants in the trip do so. Mark, too, teaches science with interest when he feels that students in the classroom become excited and engaged actively in learning activities. It is obvious that Mark becomes very excited about what is going on in the classroom, especially when students are fully
involved in the events. We observed this situation in many classes during the semester, such as the classes on temperature, on covalent bonding, and on reduction and oxidation. Mark describes his feeling when instructional strategies work effectively to maximize students’ interest and participation:

I put a lot of time and energy into it [the physical science course], especially when I am teaching my part. I take it personally and I take it hard when things don’t work, and I feel great when things do work.

Students’ Prior Knowledge

The main goal for Mark as a trip driver is that all participants in the trip enjoy learning and knowing new and exciting places and things along the way of the trip. Mark encourages students to participate actively in the trip program using their prior knowledge and experience to construct new knowledge through watching, listening, asking questions, arguing with others, and reading carefully the brochures and posters about their journey. Each participant has his or her own prior knowledge and ideas about places and things on the trip. The driver can use his experience to help participants construct new knowledge about things and places on the trip.

Within this metaphor, students are active agents on the trip to achieve the goal of learning with understanding about topics and concepts in the course. Students use their prior knowledge built by home, TV, high school, and other organizations in the community to construct new knowledge about science concepts. Learning by construction implies a change in prior knowledge, where change can mean replacement, addition, or modification of extant knowledge (Cobern, 1993). Mark commented on the importance of students to conduct a fruitful trip of learning as follows:

The teacher is in charge, the teacher sets the tone of the class...but at the same time, the students are very important. So the students can say, “Let’s go here, I want to see this,” but the teacher drives them. They say, “All right, let’s go here and spend an hour.” [The teacher may reply] “That’s a good idea,” or, “Don’t go there,” or, “Don’t stay very long,” or “No, we are not going over there, we just don’t have time, we can’t stop there.” That is the teacher’s job, but the teacher does his or her job best if he or she does it with the input of the class.
Students as Co-Participants

Since Mark’s main goal as a teacher is to maximize the participation of his students, using the metaphor of a trip as a referent for actions encourages the class community to develop interaction in the classroom. The trip community creates a shared language that permits all participants to co-participate. Co-participation implies that each of the participants shares a language and can understand what is happening to the extent that there is freedom to participate and learn with understanding (Schön, 1985). The language is negotiated and is constantly evolving as learning occurs. Mark stimulates co-participation among participants through the use of different instructional strategies. Students learned chemical concepts with understanding because they feel that they have the power to talk, ask and answer questions, and express their ideas. Tobin & Tippins (1996) emphasize the importance of creating a discourse that is shared among participants in science classes: “In a community in which co-participation is occurring there are interactions among participants in which negotiation and consensus building are apparent and learners are empowered to participate and learn because of their ability to use a shared language” (p. 715).

The data suggest that the way in which Mark perceives his roles in the classroom is embedded in the metaphor that “learning is an exciting trip.”

Changing Teaching Roles

Through the use of the trip metaphor as a referent for actions in the classroom, Mark could constrain his roles and students’ roles in science teaching and learning. In terms of the teacher’s actions, students could also construct metaphors for their roles as learners to constrain their actions and to mediate those of their teacher (Tobin & Tippins, 1996). Mark emphasized his role in the classroom as a driver for a trip:

I think my role in the classroom is to first of all [to be] the driver. I’m the expert; the person who says what we are going to do and when we are going to do it. The teacher is the person who makes decisions “on the fly” about how things are going in the classroom. That is my role as teacher.

Within the metaphor of a trip and to be consistent with his beliefs about teaching and learning, Mark considers himself as a driver for the
trip in which the participants want to enjoy and learn. Mark views himself as no more than one of the other participants in the trip, but with more experience about the route. Since he is always driving in this way, he is an expert traveler with more knowledge about exciting things and places along the way. In each trip, the driver learns more about activities that maximize participants’ enjoyment and involvement, and the activities that do not work.

In science teaching and learning, Mark feels that some activities and demonstrations—such as the dry ice, liquid nitrogen, and balloon activity described in the vignette above—are effective in the classroom, but other activities are not. Mark expresses his frustration about how the fluorescent detergent demonstration does not work in stimulating students in the classroom as follows:

I think [the fluorescent detergent demonstration] is just really neat, and I talk about how and why these fluorescent dyes are added to detergent, and how it is like a bluing agent. The dyes absorb UV light and emit high energy visible light, which masks the yellow color in white clothes. I think it is so cool. I’ve done it three times in three different courses and it hasn’t worked yet. I mean it is a cool little demonstration, but it just doesn’t work. I’ve got it in my notes that this doesn’t work, but each year I still try it because I think it is so cool. I think it is one of the neatest simple things you can do in the classroom, but it doesn’t work for the students. They basically understand it, but it doesn’t get them excited. It doesn’t get them thinking.

When the goal of a trip driver is to create environments in which participants enjoy their trip, the driver needs to use other roles to maximize travelers’ interest. Such a driver can change his role from a driver to a tour guide or a controller, for example, based on contexts and situations in the trip. Mark is able to change his actions in the classroom as the context of learning changes. The metaphor of a travel agent or a trip driver encompasses managerial roles as well as aspects of constructivist learning theory, as noted by Ritchie (1994):

The travel agent metaphor eliminates the need for several metaphors, from which to select or “switch” to, depending on the role requirement. The travel agent [as well as the trip driver] teacher encourages students to explore new routes as well as visiting well known destinations by establishing a supportive environment based on mutual respect and trust. The link between the teacher as a travel agent and constructivism helps validate the use of the metaphor in this context. (p. 296)
In class Mark shifts from one role to another within the trip metaphor as a referent for actions. In the trip of learning, Mark is able to switch his role from a driver to a tour guide, an entertainer, a learner, and a controller in order to create learning environments in which students learn science with interest. Change of teachers’ roles in the classroom was predicted by Glasersfeld (1988), when he noted that the teacher’s role “will no longer be to dispense ‘truth’ but rather to help and guide the student in the conceptual organization of certain areas of experience.” Mark’s actions shift according to the role he uses as a referent for a specific action in a particular situation to facilitate learning.

For instance, in a class to discuss a question in the last quiz about “why isopropyl alcohol is very soluble in water, but it is also an effective degreaser,” Mark uses several roles within the trip metaphor to help students learn chemistry concepts with understanding. The text of discussion in the class (Appendix) showed how Mark shifts from one role to another to stimulate student–teacher and student–student interactions to learn about dying and bleaching concepts.

**Teacher as Guide**

Mark is a guide or a facilitator when he helps students to understand the difference between the concepts of dying and bleaching (see Appendix). For example, Mark uses the “red rover, red rover, please send someone over” game to help students understand the difference between water–water and water–grease interactions. It was clear that Mark guides the students in this discourse to relate what they are learning to their previous knowledge and to their daily experiences with chemicals, such as soap, Vaseline, and waterproof mascara. To facilitate the learning of science it is essential that the teacher “infuses science into the classroom community by mediating between the languages of the child and of science” (Tobin, 1997).

**Teacher as Entertainer**

Mark is an entertainer when he tells the students about what happened to his hair as a result of dying and bleaching when he was a graduate student. Mark as a learner is clear when he tells them, “I will find out why hair turns green, chemically.” In addition, he pays attention
to students’ ideas and uses simple language to share discussion in the class. Furthermore, he is a controller when he initiates the discussion by saying, “One more time with the quiz, and we’ll go back to talk about electrolyte activity,” and ends it with, “Let’s take advantage of the twenty minutes we have left…”

**Engaged Students**

Mark’s actions of shifting from one role to another stimulate students to engage actively in the learning process. They are excited to hear Mark’s hair story, which encourages them to participate in the discussion and talk about their experiences regarding dying and bleaching. Mark encourages students to use their own language to become involved and participate in discussing, arguing, and asking questions. Such involvement encourages students to think how to relate what they are learning to their daily life experiences. A student, for example, talks about how her father used kerosene to clean grease on his hands after working on his car. Another student talks about how her sister’s hair became green as a result of swimming daily in a pool.

Students feel that they can learn with understanding through talking, arguing, asking questions, and expressing their misunderstandings. A student in the class, Muna, comments on Mark’s roles in the classroom: “I like [Mark] a lot more….He is just more down to earth. He is funny; he explains it a little more in common terms.”

Mark is an enthusiastic learner who takes an interest in the students and their learning. Use of the trip metaphor helps him to build a congenial classroom atmosphere where students feel secure to speak before their peers. Mark is an approachable teacher who does not intimidate. He should be commended for reaching out to the students in a friendly, nonthreatening manner. Students such as Muna do take an interest in chemistry because they like Mark. Students appreciate the way he speaks in the classroom, by using simple terms and everyday examples that they can understand.

**Conclusion**

Using constructivism as a referent to develop science teaching and learning in college level classes is receiving increasing consideration. A constructivist epistemology calls for a reconceptualization of what a
science teacher is and what he or she does in the classroom (Herron & Eubanks, 1996). This epistemology can be used as an alternative referent to allow teachers to frame problems in different ways and ultimately to obtain different alternative solutions (Tobin & LaMaster, 1995). Using constructivism (rather than objectivism) as a referent for teaching helps a science teacher to think of appropriate ways to conceptualize his or her roles in the classroom. Metaphor is a way that the teacher can conceptualize his or her roles in representing knowledge of teaching and learning. The term “teacher’s role” refers to how a teacher considers his or her position when he or she is teaching a particular concept in a particular context.

A science teacher in college classes can construct his/her own metaphors to describe aspects of teaching and learning. Using metaphors can help teachers think about their roles and students’ roles while teaching science. Tobin & Tippins (1996) report three significant aspects of metaphors in terms of potential applications to science teacher education. First, metaphors can be used as a way to describe teaching. Second, metaphors can be used as a referent to constrain teacher and student actions in the classroom. Third, metaphors can be used as a generative tool to build new knowledge. Using metaphors as referents to understand teaching and learning has the potential to change what happens in classrooms.

Mark used constructivism as an alternative referent to describe science teaching and learning in his classes. Accordingly, he developed a new metaphor that was consistent with his beliefs to provide a rationale for teaching science in a different way. Mark described his teaching role in terms of the teacher as a trip driver or a tour guide who helps and encourages travelers to enjoy knowing things and places on their trip. Mark utilizes this metaphor as a referent for his actions in classes to create a student-centered approach to teaching and learning in the classroom.

Mark’s main goal as a teacher is to maximize the participation of his students, and he is always looking for ways to stimulate active and varied involvement of all participants in the trip. To be consistent with his beliefs and goals that prospective teachers should enjoy their journey of learning chemistry, Mark, the driver in the journey, uses the metaphors of controller, facilitator, learner, and entertainer as referents to create pleasant learning environments. He is able to switch his actions based on which of the constituent metaphors he uses as a referent to
frame his actions and interactions and, thereby, is able to create an exciting environment for learning.

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KT: Abdullah, a doctoral student at the time, collaborated closely with Ken Goldsby, the teacher in the study and a member of Abdullah’s doctoral committee, to study Goldsby’s teaching of chemistry over several years. A new approach to chemistry teaching was being implemented in a series of courses for prospective elementary school teachers. Penny Gilmer also was a chemist in the same university as Goldsby, and she was engaged in research on Goldsby’s teaching and also her own professional practices. It is a welcome but somewhat unusual practice for college teachers to view teaching and learning as objects for research. If this practice could become more widespread, studies of college science teaching and learning, from within, could be seeds for the reform of college science teaching. Other chapters in this section report on these types of studies.

PG: I remember well how Abdullah and I would listen to videotapes and audiotapes of Ken Goldsby teaching (while I sometimes explained some of the chemistry to Abdullah), read and reread the transcripts of the classes, listened to audiotapes of interviews with freshman American females, and sifted through the NUD*IST [Non-numerical Unstructured Data Indexing Searching and Theorizing] analyses of the voluminous amounts of data to tease apart the lessons that we learned. Our chapter here is but one of them. It is amazing to me how Abdullah made this transformation of cultures and language to study the complex language of science in a university classroom.
Teaching Against the Grain

KT: Mark, the teacher in the study, was renowned for his teaching ability. However, he had a great deal to learn in terms of rethinking his roles from a constructivist perspective. Initially, he was skeptical as he thought about what he believed about learning and then what he believed as a bench chemist. The reflexive linkages between two somewhat disparate communities—educators and chemists—created a conflict for him. His approach to teaching was somewhat unique to a handful of professors in the chemistry department, and throughout the College of Arts and Sciences the trend was to teach through better transmission of information to increasing class sizes. In addition, the administration within the university favored good teaching but not at the expense of research in science. There was pressure not to allocate too much time to research in science education. So, in many respects, this chapter and others in this book by practicing scientists (Chapters 5, 6, 8, 9 and 17) are against the grain. The habitus of universities seems to support objectivism as a way of thinking about science and science teaching.

PG: Abdullah chose to study Kenneth Goldsby, my junior colleague in chemistry, as Ken Goldsby is a champion teacher who really cares about his students’ learning. Ken Goldsby took a chance to be involved in this study of his own classroom, while he was still an assistant professor. His and my inorganic chemistry colleagues might have looked unfavorably at his promotion to associate professor and granting of his tenure because they might say he could have been concentrating on his chemistry research instead of looking at his own teaching. He knew that it was important to be a part of this community of scientists and science educators involved in research in science education. He knew that he could learn from this study of his own classroom. Also he knew that what we learned from his classroom might influence others’ teaching. Kenneth Goldsby has high ideals, and he chose to participate.

KT: Mark knew a lot about good teaching in a somewhat intuitive way. He was not afraid to ask when he did not know something and he expected his students to do the same. When he heard about constructivism he certainly looked for consistencies and inconsistencies in his teaching through that theoretical frame. But when I think of Mark, I think of a person who tried to bridge the gaps between teachers and learners. I remember watching a videotape shown by Abbas and
wondering where was Mark in the picture. I could hear his voice from
time to time but could not see him at all. Then I got it. He was that kid in
the blue jeans. Wearing his baseball hat “back-to-front.” Mark was
indistinguishable from his students in that lesson. It characterised Mark
in many respects. He was a with-it teacher whose epistemology of action
was appropriate. He cared a great deal about the students and wanted
them to learn chemistry.

**PG:** I went to visit Mark’s classroom for the first day of the semester one
year when he was teaching physical science. I remember how he
captivated the students. He used a strobe light and could vary the rate of
his strobe. He had a fan going and asked the students why he could make
the fan appear to stop moving. There were gasps of amazement and
sounds of excitement in their voices and movements. He warned them
not to put their finger into the blades to test it. I remember he had a tie on
that day, and how it moved in jerky movements that really caught the
students’ attention. This is an example of how Mark got his students
excited about learning. That was just an appetizer in a series of
experiments in one day in his classroom. Mark exudes excitement and
interest for his students.

**Using New Metaphors to Connect With Students**

**PT:** Yes, that sense of excitement is evident in the account of Mark’s
teaching. What strikes me as being highly unusual about Mark as a
professor of chemistry is his concern for creating a classroom
environment that provides rich learning experiences for students. He
expects students in his classroom to learn deeply about chemistry and
learning, unlike Dr. Stern (Chapter 1), who regards the classroom as a
place of preparation (the assemblage of facts) for learning elsewhere.
Using social constructivism as a referent, Mark is keen to engage
students emotionally and intellectually in “moving toward” making sense
from a chemist’s viewpoint of phenomena that appear in their everyday
lives. Their learning is situated initially in the world of familiar
experiences. Through guided inquiry (e.g., predict-observe-explain
strategy) and co-participation in an initially highly accessible discourse,
Mark skillfully urges his students to adopt the discourse of a chemist
and, in so doing, to co-construct chemistry concepts. Other science
teachers interested in adopting social constructivism as a referent for
their own teaching practices will find Mark’s use of metaphor a very powerful and accessible strategy for understanding anew the relationship between their teaching roles and their students’ learning roles.

**KT:** Metaphor is a powerful way to organize actions. Hence by conceptualizing the teacher as provocateur, teacher and student roles can be linked as a coherent set to be enacted in accordance with the metaphor as a referent.

**PT:** Metaphor is a powerful tool that can free us from dogma, especially the dogma of thinking dualistically (see Chapter 9). Rather than believing that it is necessary to reject objectivism and replace it (ideologically) with constructivism, I believe that it is more helpful to think about how we might add to our pedagogical repertoire metaphors based on alternative referents. The power of metaphor is that it can be used to think creatively about the relationship between teaching and learning. There might be times when it is appropriate to think (metaphorically) about teaching as though it involves transmitting objective facts and about learning as absorption, especially when learning efficiently by rote recall is required. At other times, we might choose to teach that facts should be regarded (metaphorically) as human constructs that are situated historically in the development of (Western) scientific ideas, and that learning is best considered as a process of constructing fallible understandings, legitimated by community agreement.

**BIBLIOGRAPHY**


APPENDIX

A Text of Classroom Discourse Between Mark and the Students

Mark: One more time with the quiz, then let’s go back to talk about the electrolyte activity. The question about this molecule [Mark points to the structure of an isopropanol molecule on the board and continues discussing the answer]…So isopropanol doesn’t really act like a soap. And you know that. When you use isopropanol, it doesn’t suds up and it doesn’t make a foam. But it is a good degreaser and people often use it as a, as a, a…

Student 1: Astringent.

Mark: Astringent. Thank you. Isopropanol is the cheapest astringent that you can use. [You know] it’s soluble in water because rubbing alcohol is a mixture of isopropanol and water…[Mark continues using the chalkboard to draw a structure clarifying the relationship between isopropanol, water, and degreaser.] There was an implication that the grease would go to the carbon, and that’s not really right, the grease goes to the nonpolar part of the molecule. It is this whole part right here that’s nonpolar. Does that make sense? The combination and application of the…

Student 2: What part is the nonpolar part?

Mark: The part that is nonpolar. The part that has carbon-hydrogen bonds…[Mark goes back to the board to clarify which part is polar and which is nonpolar in the structure of the molecule.]

Student 3: So doesn’t a carbon have something in the middle…I mean…because they’re the only ones that can…
Mark: Maybe only one that...if the grease went into the water, it moved here to break up the strong water–water interactions. Therefore there’s no grease because the interaction between the hydrocarbon and the water is very weak, compared to the interaction between the water and water. Imagine you...played red rover, red rover, please send someone over, and you line up and hold hands. What’s the rule to that game?

Students: You have to try to break the barriers.
Mark: If you break through you’re free. If you don’t break through, you’re captured. When you call someone over to play, do you pick the big kid or the small kid?
Student 4: The small kid.
Mark: You pick the small kid because the small kid doesn’t have the energy to break that interaction. But water molecules have a very tight hold on each other. The only thing that’s going to break it up is something which has a strong interaction with water, like a polar molecule, like this OH group, like an ion, that’s something that’s going to break up water...

Student 5: So if the outer edges were blocked because they were larger molecules...they have to bond with O and H?
Mark: Yeah, that’s right. This part is a hydrogen bond...
Student 5: How do you know that grease is attracted to the hydrocarbon?
Mark: The question is how do you know that grease is attracted to this part of the molecule. I would think that it’s common knowledge. Give me an example. I mean, can you think about something you do know that you’ve done that involves grease being attracted to molecules like that?

Student 6: The thing when we make soap?
Mark: Yeah, the soap, you don’t know which end is doing it. So let’s pick something which is just a hydrocarbon.
Student 7: Is it because they’re both nonpolar?
Mark: Okay, that’s why it happens, but it doesn’t answer the question, “How do I know that works?”
Student 1: How about water, I mean you put grease in water, you know like if you’re boiling, getting ready to do spaghetti noodles…

Mark: The grease floats on the top. So you know the grease doesn’t go underwater. That tells you it doesn’t interact with water, grease interacts with hydrocarbon. Let’s think about this example: Did you ever have grease on your hands working on a car or something like that? What do you use to clean them off? Ever used kerosene?

Student 8: My dad used to do it.

Mark: You’re painting with an oil-based paint. What do you clean the brushes with?

Student 4: Mineral spirits.

Mark: Mineral spirits. Mineral spirits is hydrocarbon. It’s like gasoline. Let’s use the mascara example, when you are trying to take waterproof mascara off, which is greasy, that’s why it is not soluble in water, it’s a grease. Water doesn’t do a very good job. Somebody mentioned Vaseline, which is kind of hard to get out. When I was a kid, when I was in high school, they had a fifties party. Everybody slicked their hair back. I didn’t have anything to do that, so I used Vaseline. [Students are laughing.] Do you know how long it takes to wash Vaseline out of your hair? If you wash your hair three times a day, it takes exactly twenty days to get the Vaseline out of your hair. [More laughing in the class] For a party in college, I wanted to go as a beach bum, so I dyed my hair blond, or tried to. I bought the lightest blond dye you could buy, put it in my hair. It didn’t lighten it at all. So I rooted around the medicine cabinet and got hydrogen peroxide. I dipped my hair in it very carefully, [but the hydrogen peroxide] didn’t touch it. [Students became excited] What am I going to do? I am a chemistry major in graduate school. I know how to solve all these problems. I take the towel, I soak the towel in hydrogen peroxide, wrap my hair with it and take a nap. Wake up two hours later, my hair turned orange. Flaming Richie Cunningham orange, [Students are very excited] which kept getting lighter and lighter over the next month.
Student 6: Did you shave your head? [Students laugh]

Mark: What I did was, I went to this party, and heard from at least five different people, “I had a cousin who did that once and all his hair fell out,” or, “all her hair fell out.” That’s when I learned what it takes to make hydrogen peroxide a good oxidizing agent. Every bit of what we’re talking about now you’re going to understand in terms of the simple chemistry in this class: acid-base chemistry reactions. Then I ended up at the time being a red hair for a couple of redox (reduction-oxidation) weeks. What I did was, I dyed my hair black. When I bought the blond dye, I bought the black dye also, I dyed my hair black after the party, so a couple of months later, when the dye started to wear off, I started having black roots with black and orange hair. That’s back before people did that on purpose, so then I got a really short haircut. The reason why I am telling you the things I did is I am trying to think of things you might have done, use the makeup, clean the grease off your hands, because I think you can make sense of things you had experience…

Student 9: Okay, let’s say I wanted to dye my hair blond, and I applied everything, and I came out with green hair, what went wrong?

Student 10: My friend did it, she had blond hair, and she wanted to dye her hair black, and it turned green.

Student 9: You’re supposed to do it strand by strand.

Mark: Let me tell you what I learned about this.

Student 3: What if you sprayed lemon juice in your hair, what color would it turn? [Students were giving their answers all at once.]

Mark: Every point I’m trying to get across, every bit of this, you can understand in terms of the chemistry that we’re talking about.

Student 10: Why if you have blond hair and a light color hair, and you swim like in the summer and you have chlorine, why does your hair turn green?

Mark: This is so cool. Let’s talk about this. You’ll get a short answer and then with a promise we’ll come back to this.
When a person dyes their hair blond, what do we call that process? What do they do to their hair?

Students: Bleaching.

Mark: Bleaching. Dying is something different from bleaching. When you dye something you put a different color over it. When you bleach something you take the color out. When you want to bleach your clothing to take out stains, to take out color, or when you accidentally, or in my case when you are washing the colored clothes and you forget that you don’t put the Clorox in those. [Students laugh.] What are you doing to them? You’re also bleaching, right? What do you add to clothes to bleach?

Students: Bleach.

Mark: You add bleach, you add Clorox. What do you add to a pool to kill the microbes?

Students: Chlorine.

Mark: Chlorine. Same thing, the chlorine that you add to the pool is chemically the same thing as the Clorox that you add to your clothes. They are both oxidizing agents, oxidizing agents are molecules that rip electrons out of things….When you combine an oxidizing agent with an acid it becomes a better oxidizing agent and you bleach your hair better.

Student 5: My mom used to tell me when I was little, I had a lot longer hair, she used to say that if you wet your hair down with a hose before you put something...

Student 9: I think if you cut it up into...

Mark: I think you’re making up this green stuff. [Students argue that it is possible that your hair can turn green.] Who here would be willing to do that? I would like to see this.

Student 10: I have pictures of when I was little, I can bring to you, with green hair.

Mark: And you didn’t dye it green because of a party.

Student 11: If you swim every day and you don’t rinse your hair, you don’t rinse the chlorine out of your hair [students give their explanations all at the same time].
Student 9: It’s not green like her jacket (pointing to a student’s jacket)
Student 12: It’s like a green tint.
Student 13: My sister was platinum blond and she was a swimmer, she swam every single day of the week, her hair turned green.
Student 3: I used to be a lifeguard, and little kids used to come to the pool and their hair used to be that color, I mean their hair was green.
Mark: I could deal with it, I will find out why hair turns green, chemically….I will find out chemically why hair turns green. If you guys work as hard as you can to apply the level of enthusiasm and interest that you applied to this conversation [students are laughing], then on Monday we’ll do makeovers [students still laughing]. Aren’t you impressed with what I know about makeovers, there’s a term I don’t get to use in my speech every day; let’s take advantage of the twenty minutes we have left.