SCIENCE TEACHER EDUCATION

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Using Pedagogical Inquiries as a Basis for Learning to Teach: Prospective Teachers' Reflections Upon Positive Science Learning Experiences

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ABSTRACT: The primary purpose of this study was to document and interpret ways in which the first author engaged prospective teachers in pedagogical inquiries and then assisted them in using their findings as a basis for learning to teach in her courses on methods of teaching science in elementary schools. The focus here is upon inquiries about factors that foster science learning. A second purpose was to trace some of the effects of such a pedagogical approach in the development of expertise in teaching, researching, and mentoring. A third purpose was to contribute to the development of interpretative methodology, an example of a collaborative inquiry. Data included drawings made by prospective teachers on the first day of class in which they depicted memories of positive experiences in learning science. They also wrote captions for their drawings, identified factors that fostered their learning in these instances, and constructed a joint list of factors

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across these individual experiences. Throughout the semester, the prospective teachers also wrote journals describing science learning they observed and analyzing factors that fostered learning in those instances. Then they analyzed their own journals for common themes in order to develop personal frameworks for science teaching and learning. Data also included audio-taped interviews and written reflections by a graduate of the course about ways the course has influenced her evolving teaching and mentoring practices. The results suggest that these prospective elementary school teachers had entered a course on methods of teaching science with prior knowledge about science learning and teaching that could serve as a basis for learning to use approaches to science instruction advocated in the national standards. The reflective methods utilized in the course enabled at least one of these prospective teachers to articulate her philosophy of teaching in ways that helped her instantiate such practices as a beginning teacher. © 2001 John Wiley & Sons, Inc. *Sci Ed* 85:733–757, 2001.

INTRODUCTION

The primary purpose of this study was to document and interpret ways in which the first author engaged prospective teachers in pedagogical inquiries and then assisted them in using their findings as a basis for learning in her courses on methods of teaching science in elementary schools. What, for example, do prospective teachers already know about factors that foster science learning when they enter a course on methods of teaching science? They enter such courses with ideas about teaching and learning based upon their own experiences in schools, just as students enter science subject-matter courses with ideas about natural phenomena based upon their experiences in the world.

For the past two decades, a major emphasis in science education research has been on characterizing difficulties students encounter: What are the common misconceptions in each science subject-matter area and how can these be overcome (Helm & Novak, 1983; Novak, 1987, 1993)? A similar emphasis has been placed on prospective teachers' preconceptions. Atwood and Atwood (1996), for example, documented prospective teachers' misconceptions about the causes for seasons, many of which are similar to those of children.

More recently, however, some researchers have begun to emphasize positive aspects of prior experiences. The importance of accessing students' intuitive knowledge has been stressed in contexts from kindergarten children learning about numbers (Griffin, Case, & Siegler, 1994) to high school students learning physics (Minstrell, 1992): What are the intuitions that can serve as anchors for further learning (Clement, Brown, & Zietsman, 1989)? How can students' useful intuitive knowledge be expanded and refined (Smith, diSessa, & Roschelle, 1993/1994)? What are the resources upon which students can draw in analyzing complex physical phenomena (Hammer, 2000)? This study is in that positive tradition. It documents prospective teachers' prior knowledge about successful science pedagogy, and describes ways in which the prospective teachers can use such knowledge as a basis for learning in a course on methods of teaching science in elementary schools.

A second purpose of the study was to trace some of the positive long-term effects of eliciting reflections about successful science learning experiences in developing expertise in teaching, researching, and mentoring. The first author has described her intents and purposes in engaging prospective teachers in pedagogical inquiries, and illustrated these with responses drawn from the second author's writings while she was enrolled in the course. The second author has reflected upon ways in which her findings influenced her subsequent development as a student teacher, beginning teacher, and mentor teacher. A third purpose of the study was to provide an example of such a collaborative inquiry. This is "a mutually constructed story" (Connelly & Clandinin, 1990, p. 12) created out of the lives of a teacher and university researcher.

This study contributes to the literature on reflective approaches to teaching and, in particular, to teaching teachers. Dewey (1933) viewed reflective thinking as a way to come to understand situations, particularly puzzling ones, by making observations to clarify what is happening and perceiving, considering, and testing various possibilities. A half century later, Schön (1983, 1988) articulated a theory of reflection that included both reflection-in-action ("undertaken in the midst of action to guide further action" (Schön, 1988, p. 22)) and reflection-on-action ("carried out . . . after the fact, to yield . . . carefully documented stories that contribute to usable repertoire (and) theories that offer perspective on practice; to be tested in the next instance of reflection-in-action" (Schön, 1988, p. 24)). In applying his ideas to education, Schön defined reflective teaching as (Schön, 1988, p. 19).

> . . . listening to kids and responding to them, inventing and testing responses likely to help them get over their particular difficulties in understanding something, helping them build on what they already know, helping them discover what they already know but cannot say, helping them coordinate their own spontaneous knowing-in-action with the privileged knowledge of the school.

Instructors in courses on methods of teaching science can apply this vision of reflective teaching by creating opportunities for prospective teachers to express their own views, by listening and responding to what they have to say, by designing ways to help them get past the fears with which many enter a course on methods of teaching science, by helping them to build upon their positive science learning experiences and to articulate what they already know about successful science pedagogy, and by engaging them in teaching and learning experiences that they can then use to make sense of district, state, and national standards for science teaching. This is the perspective taken by the first author in designing the course described later.

Reflective practices have been incorporated in courses on methods of teaching science in many different ways (Posner, 1985). Abell, Bryan, and Anderson (1998), for example, identified four contexts for a reflection orientation (reflecting on others' teaching, reflecting on one's own teaching, reflecting on expert opinions, and reflecting on self as science learner), and investigated prospective teachers' reflective thinking through analysis of their responses to video cases in class. Nichols, Tippins, and Wieseman (1997) described an array of "tools" such as portfolios, journals, classroom cases, learning maps, stories, metaphors, and proverbs for developing critically reflective teachers. Roychoudhury, Roth, and Ebbing (1993) traced an elementary student teacher's endeavors to become a reflective teacher through reframing a problem and making some of her tacit knowledge explicit. Teacher educators who model reflection explicitly through sharing their journals and talking about their own teaching in class can help student teachers to develop reflective practices (Loughran, 1996). An important component of reflection extends beyond the classroom and recognizes the social context of teaching (Zeichner & Liston, 1996).

Many reflective practices resemble methods used in interpretative research. Cronin-Jones (1991) advocated using even quite sophisticated methods, such as the repertory grid technique (Kelly, 1955), as tools for educating science teachers. Collecting and interpreting data about student thinking can help prospective teachers shift their focus away from themselves as teachers to their students as learners (Tabachnick & Zeichner, 1999). Using the language of research in methods courses can help prospective teachers begin to view themselves as researchers (Downey-Skochdopole & Goldston, 2000). In the *National Science Education Standards*, the National Research Council (NRC, 1996) recommended that professional development for teachers of science requires "building understanding and ability for lifelong learning . . . (professional development should) provide opportunities to learn and use the

skills of research to generate new knowledge about science and the teaching and learning of science" (p. 68). The first author has designed a course that addresses this recommendation by teaching prospective teachers how to do research as they learn how to teach (van Zee, 1998a, 1998b).

This study presents an example of incorporating a research activity into instruction and using the findings as a basis for further learning. The activity involves the qualitative research technique of eliciting experiences from a variety of individuals and identifying common themes (Strauss, 1987). The findings themselves are of interest as evidence of the knowledge that prospective teachers bring to their study of methods of teaching science. The study also presents an example of reflective research, in which an individual traces influences of an experience through a narrative account of her developing expertise in teaching, researching, and mentoring.

The specific research questions that guided the study were the following:

- How can pedagogical inquiries serve as a basis for learning how to teach?
- In particular, what kinds of experiences do prospective elementary school teachers remember when asked to think about positive experiences learning science at any time in their lives, in any place, with anybody? What was the nature of these experiences? Where did they occur? Who was involved?
- What do prospective teachers think were the factors that fostered their learning in these instances?
- How can prospective teachers develop a personal framework for teaching science through a sustained inquiry into factors that foster science learning?
- How did developing such a personal framework for teaching influence the development of a participant's expertise in teaching, researching, and mentoring?

METHOD

This study is an example of research conducted by instructors in the context of their own teaching practices (Cochran-Smith & Lytle, 1993; Hitchcock & Hughes, 1995; Hubbard & Power, 1993, 1999). The first author, Emily, is reporting upon data collected in her courses on methods of teaching science in elementary schools. The second author, Deborah, is reporting upon her experiences as a student in that course during Fall 1995 and upon her subsequent experiences as a student teacher, beginning teacher, and mentor teacher.

Participants

Participants include prospective elementary school teachers enrolled in Emily's courses on methods of teaching science. We selected two classes. We chose the Fall 1995 class ($n = 28$) so that we could use Deborah's responses as illustrations of the pedagogical inquiries enacted during the course. We chose the Fall 2000 class ($n = 22$) so that we could comment upon ways in which Emily is currently conducting the course. In both classes, the prospective teachers were primarily white females of typical college age. Both classes also included a few representatives of African American and Asian cultures and several white women returning to school while raising children. The Fall 2000 class also included four white male students of typical college age.

Emily is a science education faculty member at a Mid-Atlantic research university. She has taught middle school science, participated in research, curriculum development, and instructional projects (McDermott, 1996; Rutherford, Holton, & Watson, 1965), collaborated with teachers in studies of questioning during conversations about science (van Zee, Iwasyk, Kurose, Simpson, & Wild, in press; van Zee & Minstrell, 1997a, 1997b), and sponsored a teacher researcher group (van Zee, 1998a, 1998b). Deborah was one of the prospective teachers in the Fall 1995 class, completed her student teaching in Spring 1996, and has been teaching full-time since September 1996. She has participated in the founding of a teacher researcher group, presented at national conferences, and published accounts of research in her own classroom (Roberts, 1997, 1998, 1999, 2000).

Settings

The elementary science teaching methods course was one of five in a block of courses taken the semester prior to student teaching. The other courses provided instruction in methods of teaching reading, language arts, mathematics, and social studies. The prospective teachers spent 2 days on campus and 2 days in their placement settings weekly; they also spent all day every day in the schools for a week near the beginning of the semester and for a second week near the end of the semester. Their placements were in suburban elementary schools with diverse populations, where typically more than half of the students were eligible for reduced or free lunch. Deborah taught in one of these elementary schools during 1996–99 and is currently teaching in a middle school in the same area.

Data Sources

Data sources included drawings, written responses, and posters constructed by prospective teachers in the Fall 1995 and Fall 2000 classes, our audio-taped research conversations, Emily's written reflections, and copies of Deborah's writings as a student in the course and as a researcher in her own classroom.

Interpretive Approaches

Emily used several interpretive approaches (Gallagher, 1991) in documenting ways in which she used pedagogical inquiries as a basis for learning to teach in her courses on methods of teaching science in elementary schools. As an instructor reflecting upon her own practices (Hubbard & Power, 1993, 1999), she wrote narratives explicating her design for instruction and the reasoning underlying this design. She also collected and interpreted her students' work. In addition, Emily traced one participant's progress by quoting her responses as examples in the narrative about the course and by inviting her to write reflections upon the long-term influences of experiences in the course. In recognizing this individual as a coauthor, rather than anonymous subject, she engaged in a collaborative inquiry, in which both instructor and student/colleague participated in developing and articulating interpretations. This process is a form of autobiography (Solas, 1992) in which efforts toward educational reform are grounded in examination of personal experiences and values. This account also represents an example of the scholarship of teaching (Hutchings & Shulman, 1999) in which faculty make public their findings from documentation and analysis of their own teaching practices.

The prospective teachers' responses on the first day of class included both drawings and written comments. Drawings have been used to probe understanding for many years (White & Gunstone, 1992). Travers and Rabinowitz (1957), for example, used drawings of teachers teaching as a measure of teacher personality. Mead and Metraux (1957) and Chambers (1983) identified stereotypical features of students' views of scientists through a draw-a-scientist task. Emily invited the prospective teachers to draw pictures of experiences in which they had enjoyed learning science. The prospective teachers also wrote captions describing their pictures. We categorized these responses in terms of the science disciplines, settings, technology, social contexts, and facial expressions depicted. We selected these categories

on the basis of our own curiosity about the prevalence of life, physical, or earth science contexts, inside or outside school settings, types of specialized equipment used, individual, small group or large group activities, and apparent emotional responses represented in these drawings.

In addition to drawing pictures and writing captions, the prospective teachers identified factors that had fostered their learning in these instances. Participants in each small group then constructed a joint list of factors that had fostered science learning across their individual experiences. In addition, the Fall 2000 class identified common themes across all of the small groups' lists of factors that fostered science learning. In inviting the prospective teachers to analyze their responses in this way, Emily engaged them in identifying common themes in interpretations of their experiences (Strauss, 1987).

In a form of narrative inquiry (Connelly & Clandinin, 1990; Cortazzi, 1993), Deborah prepared an account that reflected upon her experiences as a student in the course in Fall 1995, as a student teacher during Spring 1996, and subsequently as a beginning teacher and a mentor teacher. Her narrative is not intended to represent the entire cohort of students in her class. Rather her account provides an individual example of ways in which pedagogical inquiries can have a long-term influence in developing expertise in teaching, researching, and mentoring.

PEDAGOGICAL INQUIRIES

We begin with a narrative in which Emily discusses ways in which she used pedagogical inquiries as a basis for learning to teach science in elementary school. By pedagogical inquiries, we mean explorations of issues relevant to learning and teaching. Emily has used responses by Deborah and her classmates to illustrate such inquiries. Then we present a narrative in which Deborah articulates long-term influences of engaging in pedagogical inquiries on her developing expertise in teaching, researching, and mentoring

Using Pedagogical Inquiries As a Basis for Learning to Teach (by Emily van Zee)

My instructional approach can be considered to be constructivist (Fensham, Gunstone, &White, 1994) in that I attempt to elicit my students' prior knowledge about science pedagogy and then to assist them in making sense of new ways of thinking about teaching that I hope to engender. As discussed later, I opened the course with an activity in which the prospective teachers reflected upon their positive experiences in learning science and identified factors that had fostered their learning in these instances. In addition, I facilitated a sustained inquiry into science learning-in-progress in order to help the prospective teachers develop personal frameworks for science teaching and learning.

Inviting Prospective Teachers to Reflect Upon Their Positive Experiences in Learning Science. In designing instructional activities, I wanted to address head-on the anxieties with which I believed many of the prospective teachers would be entering my course on methods of teaching science. I was aware that many elementary teachers choose not to teach science and that elementary education majors often have had negative experiences in science courses (Abell et al., 1998; Jablon, 1994). Yet, I believed that there must be some contexts within which the prospective teachers had learned science and had enjoyed the experience. I hoped to demonstrate that such experiences were valuable resources in developing their own personal frameworks for science teaching and learning.

The "draw-a-scientist" studies (Chambers, 1983; Mead & Metraux, 1957) provided the inspiration for my decision to invite the prospective teachers to draw pictures of positive experiences they had had in learning science. Although the drawings of scientists had yielded largely negative information in terms of stereotypical features that students typically included, I thought that the power of such visual displays could be turned to more positive purposes. Vivid drawings of successful science learning experiences could focus attention upon what had worked well for these prospective teachers. Identifying common themes in these examples of successful science learning could yield findings that they might find more convincing than simply reading about recommended methods for teaching science in their textbooks or in state and national standards documents. I also wanted to model incorporating art into science instruction. In addition, posters of positive science learning experiences could serve as reminders all semester long of ways to teach science effectively.

On the first day of class, I invited the prospective teachers to think back over their lives both inside and outside of schools and to remember some of their more positive experiences learning science. I also asked them to draw pictures of these positive science learning experiences, to write captions for their pictures, and to list factors that fostered their learning in these instances. The first prompt was "Think about some of the better experiences you have had in learning science. Please draw a picture of one of these experiences in the space above. Write a caption for your picture." The second prompt was "What factors were important in fostering science learning for you in this instance?" Then prospective teachers in each small group taped their pictures to a poster and constructed a joint list of factors that had fostered their learning. Finally, the prospective teachers in each group introduced themselves to the whole group by showing their poster and reporting their findings. This process was the same for both classes, with one exception. After the small groups had shared their joint lists of factors that fostered science learning, the prospective teachers in the Fall 2000 class constructed a list that represented the thinking of the entire class.

An example of a prospective teacher's drawing is shown in Figure 1. Deborah had illustrated a session during her college physics course in which she and two partners had designed an experiment to explore heat and temperature. Her caption reads, "Do marshmallows "melt"? When added to hot chocolate, do they change the temp?" She was reflecting upon a course that a physics professor, John Layman, had designed to engage prospective teachers in inquiry. The course was part of a state-wide effort to reform undergraduate courses preparing elementary and middle school teachers in mathematics and science (Gardner & Ayres, 1998; Krajcik & Layman, 1993; Layman, 1996)

Deborah and her group members taped their drawings on a poster. One had illustrated "hands-on" science in which she had worked with beakers and test tubes of liquids. Another had drawn a picture of herself presenting a science fair project on adolescence in eighth grade. The third had drawn a picture of a volcano with a caption that read "In fourth grade, I made a volcano with paper mache and baking soda. This is the only science experiment I *remember* from elementary school. I was very interested in archeology and paleontology but we never covered it meaningfully. I also did a science project on hypnosis in 8th grade which I won an award for."

Table 1 presents a list of the activities depicted in the students' drawings for the Fall 1995 and Fall 2000 classes. The activities occurred in elementary school (e.g., hatching eggs), middle school (e.g., flying hot air balloons behind school), high school (e.g., breeding flies), and college (e.g., using a computer and motion detector to study motion). Table 2 presents an analysis of the science disciplines, settings, use of technology, social contexts, and facial expressions shown. The prospective teachers remembered positive experiences mostly in the context of the life sciences and physical sciences, with only a few in earth and space sciences or the social sciences. The most common settings were class activities such as mixing chemicals and field trips such as exploring a nearby stream. A few drew pictures of special events at school such as an egg drop contest and science fairs. A few included specialized equipment such as a microscope or telescope in their pictures. Only one drew

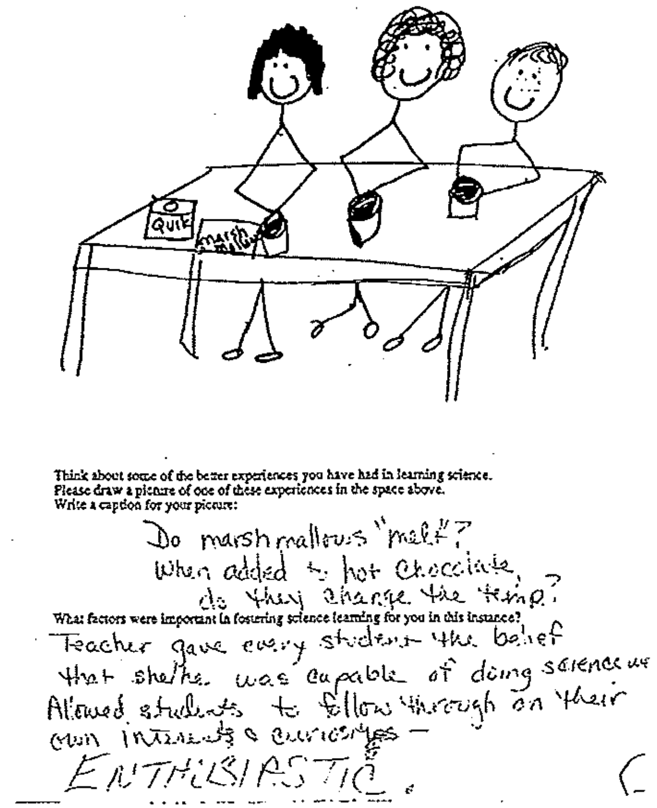

Figure 1. Drawing of a positive science learning experience.

a picture of a computer. Many chose not to include figures in their drawings. Two depicted large groups, however, one at a Planetarium and the other at a visit to the school of Skylab. Some drew small groups of students doing something such as identifying leaves. Some drew an individual, presumably a self portrait, doing something such as looking at a cell in a microscope. Six included a figure representing a teacher—doing demonstrations such as refracting light with a prism, leading a small group on a field trip, or standing behind a lectern lecturing. When facial expressions were included, most were smiles. The most expressive faces are shown in Figure 2. Three students are dissecting a snake: one mouth is smiling, one is a circle perhaps showing surprise, and one is a horizontal squiggly line that suggests consternation.

TABLE 1
Positive Science Learning Experiences Drawn by Prospective Elementary School Teachers

Scenes Depicted by Fall 1995 Class	Scenes Depicted by Fall 2000 Class
Life sciences	Life sciences
going on a nature walk (self)	looking at a cell in a microscope (self)
testing water quality of a lake (self)	dissecting a frog
studying plants and animals outdoors (self + 2 others)	collecting leaves (self)
identifying leaves (self + another)	exploring wetlands (no people shown)
dissecting a pig (2 drawings)	exploring stream at outdoor education center (self)
dissecting a snake (self + two lab partners)	studying life in nearby creek (self)
studying biology	canoeing through salt water marsh (2 stick figures)
breeding flies	boating at educational camp (4 stick figures)
hatching eggs	measuring speed of stream (self)
	visiting fossil bearing cliffs (5 small stick figures for students, 1 larger figure, teacher)
	hunting sharks teeth at beach near fossil-bearing cliffs (3 stick figures)
	visiting bee farm (self)
Physical sciences	Physical sciences
cooking on a Brownie Bunsen burner (self)	dropping a protected egg off a roof (3 stick figures)
mixing liquids (self)	launching a rocket (self)
"melting" marshmallows in hot cocoa (self + 2 lab partners)	releasing hot air balloons (4 stick figures)
making a "volcano"	studying light with a prism (professor)
mixing chemicals (teacher)	dissolving penny in acid
mixing chemicals (teacher + 3 students)	making rock candy
heating beaker with chemicals	
pouring liquid N on floor (teacher, self)	
making sugar crystals	
studying motion with motion detector	
standing hair up with static electricity (self)	
Earth and space sciences	Earth sciences
collecting rocks (self + friend)	problem solving with satellite landings
going on a geology nature walk	
walking through caverns	
studying the stars in SkyLab (13)	
studying the stars in a Planetarium (10)	
looking through a telescope (self)	
watching an asteroid collide with Jupiter	
Social sciences	Social sciences
Presenting science fair project on adolescence (self)	Drawing a family pedigree
	General
	presenting at a science fair
	lecturing (professor)

(Parentheses indicates person/people shown in drawing; assumes drawing of self)

TABLE 2
Prospective Teachers' Descriptions of Positive Science Learning Experiences

	Fall 1995 Class	Fall 2000 Class
Science disciplines		
Life sciences	10	13
Physical sciences	11	6
Earth/space sciences	7	1
Social Sciences	1	1
General	0	2
Settings		
Class activities	16	8
Field trips	8	10
Special events at school	1	3
Science Fair	1	1
Youth group outing	1	0
Professor lecturing	0	1
News event	1	0
Technology (use of specialized equipment)		
Microscope	1	1
Telescope, skylab, planetarium	3	0
Computer with motion detector	1	0
Electrostatic generator	1	0
Gas bunsen burner	1	1
Dewar of liquid nitrogen	1	0
Water quality test kit	1	0
Graduated cylinder	0	1
Beaker, flask	1	1
Incubator	1	0
Social contexts:		
Large groups (10 or more figures shown)	2	0
Small group with teacher (5 stick figures, plus one larger stick figure)		1
Small groups (2–6 figures shown)	7	6
Individual (1 figure shown, student)	7	7
Individual (1 figure shown, teacher)	1	2
No figure shown	12	7
Facial expressions:		
Smiling	20	8
Round with surprise	2	0
Open while talking	0	1
Squizzled with puzzlement	1	0
Straight with concentration	0	1

Inviting Prospective Teachers to Identify Factors That Fostered Their Science Learning. In addition to drawing pictures of positive experiences and writing captions, the prospective teachers identified factors that fostered their learning in these instances. Deborah, for example, wrote the following about her college physics course: "Teacher gave every student the belief that she/he was capable of doing science well. Allowed students

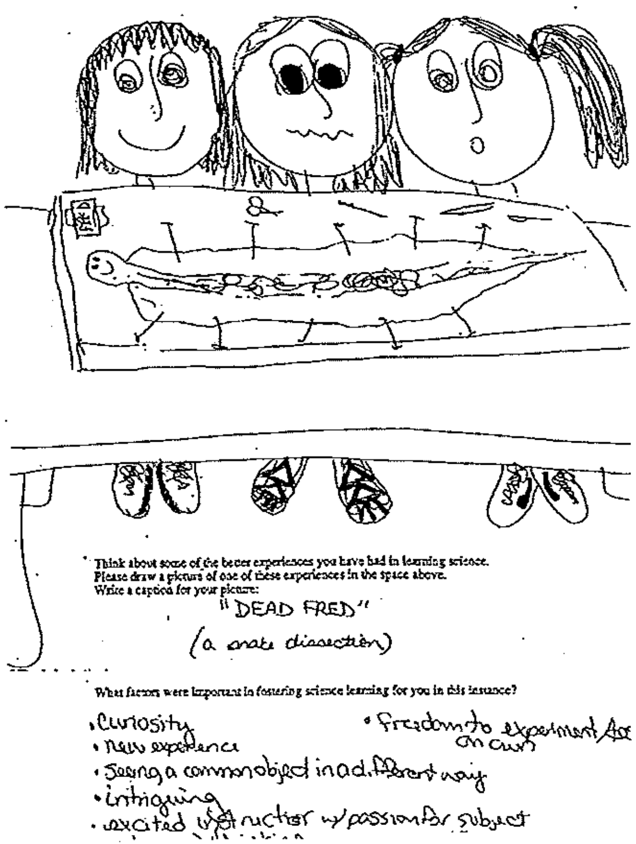

Figure 2. Expressive faces during dissection of a snake.

to follow through on their own interests and curiosities—ENTHUSIASTIC." The group member who had drawn herself mixing chemicals identified important factors as "it was hands-on, interesting—not just facts and formulas. It was real and natural and easy to understand (not like chemistry and physics)." The science fair presenter identified important factors as "topic was relevant to my age group; I was experiencing the things I learned." The volcano maker identified important factors as "Discovery learning and hands on made these experiences meaningful. I *produced* something. It doesn't *work* to just read about it in a text book!" (emphasis in the original)

While constructing their poster, Deborah and her group members identified the following joint list of factors that had fostered their science learning in these particular instances:

- relevant topic
- age appropriate
- hands-on
- easy to understand
- produced something
- discovered and experienced new phenomena
- teacher "empowered" and "enabled" students
- student generated experiment
- teacher enthusiasm

This list represents knowledge about science learning and teaching with which these prospective teachers had entered my course and could use as a basis for learning to teach.

During the first session of the Fall 2000 class, I asked the prospective teachers to take an additional step: identifying common themes across all of the groups. They generated the following class list of factors that had fostered their science learning:

- hands-on
- group work
- engagement
- observations
- positive teacher involvement
- "out" of classroom
- investigations
- exploration
- fun/dirty
- relevant to the student
- thought provoking
- teacher caring and preparation

After the prospective teachers had identified these factors, I asked whether these were typical of their science learning experiences. Most responded negatively and I suggested that such findings indicated the need for reform. I also commented that their factors fostering science learning were closely aligned with recommendations by various authorities and that we would be making connections to these throughout the semester. Thus, I was able to make a direct link between these prospective teachers' prior positive experiences and the handouts I was providing with excerpts from the *National Science Education Standards* (NRC, 1996), *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993), and the Maryland School Performance Assessment Program. I also noted that we would be making many connections among these factors that they had identified and issues raised in our texts (Krajcik, Czerniak, & Berger,1999; Saul et al., 1993) and in literature that I had placed on reserve for their use (such as Driver, Guesne, & Tiberghien, 1985; Gallas, 1995). In addition, I used this list to explain how I planned to teach the course: by engaging them in "hands-on" teaching experiences in which they would explore pedagogical issues collaboratively in small groups, both in class and in elementary school classrooms, in what I hoped would be thought provoking ways.

The class list of factors that foster science learning guided the prospective teachers in the Fall 2000 class in their design of lessons throughout the course. During the second week of the semester, they reported these findings to experienced teacher researchers at a research festival, and then used the list to guide collaborative design of lessons they conducted in these teachers' classrooms (van Zee, Lay, & Roberts, 2000). Later in the semester, they used this class list as an assessment tool to reflect upon whether they were enacting these factors that foster science learning in their own teaching of peers in class and of children in their school placements.

Facilitating a Sustained Inquiry in Order to Help Prospective Teachers Develop Personal Frameworks for Science Teaching and Learning. The opening activity described previously demonstrated the kind of thinking that I asked the prospective teachers to do throughout the semester in journals in which they reflected upon science-learning-in-progress. First, they described science learning events that they had observed or experienced, and then they analyzed factors that fostered learning in those instances. One of Deborah's reflective journals is shown in Figure 3. She described the learning environment in her college physics course in which the students had explored physical phenomena in small groups. She noted that

> Whenever we had an idea that was a deviation from the original direction of the experiment, Dr. Layman encouraged us to follow that idea and see what we learned. I remember carrying around a paper wad with a paper clip gently attached to it for two weeks because my lab partner and I wanted to know if the smooth surface of metal balls had an effect on how the pendulum swung.
>
> *Roberts, Journal #3, Fall 1995*

This statement has been underlined in Figure 3 to highlight its presence in this journal.

At the end of the semester, the prospective teachers analyzed their own journals to identify common themes (Strauss, 1987) and to develop personal frameworks for science teaching based on this analysis. On the last day of class, the prospective teachers highlighted sentences in their journals that stated factors that fostered science learning, cut these out, sorted them into piles, taped similar statements to the same page, and then wrote a claim based on the statements. An example is shown in Figure 4; the highlighted statement from the journal shown in Figure 3 is taped at the bottom of this page. Deborah also taped similar statements cut from other journals. At the top of the page appears her claim, "Science learning allows students to follow their curiosities." Her other claims were "Science learning needs to be hands-on," "Science learning needs real-world connections," and "Science learning takes place with dedicated, caring, teachers who develop sense of community." Each of these claims was supported by evidence drawn from statements cut from her journals.

Through this sustained inquiry into science learning, the prospective teachers built their personal frameworks for science teaching. For the take-home final, they presented lessons of their choice and discussed how they would meet their recommendations for science teaching in this context. An excerpt from Deborah's final is shown in Figure 5. She chose to present a design for a conversation about ambient temperature, similar to an activity she had enjoyed in her physics course. In commenting upon how she would meet her recommendation, she wrote

> The second claim is that science learning allows students to follow their curiosities. In this experiment I need to be prepared for some questions that are tangential to come up . . . I need to be prepared to allow them to follow some of these tangents, and to put others aside for future learning or individual investigation.
>
> *Roberts, Final, Fall 1995*

Science Learning in Progress #3 Debi Roberts

An interesting science experience I had was in Dr. Layman's class in the fall of 1994. We were studying motion and the pendulum. We were each given a pendulum and several balls. We all had seen pendulums before and had to make predictions about how the weight difference in each of the balls was going to affect the behavior of the pendulum. We were also asked to take into account any previous experiences we had had studying motion in his class. We made our predictions and then with the use of the computer graphed our results. We were then encouraged to change the length of the string, and vary the distance at which we released the ball to start the pendulum swinging. Then we had to devise an experiment to validate (or eradicate) our hypothesis.

As always in Dr. Layman's class, initially I felt a little frustrated. But as my lab partner and I got further and further into our explorations, we became totally involved in what we were doing, and less concerned with being right. Whenever we had an idea that was a deviation from the original direction of the experiment, Dr. Layman encouraged us to follow that idea and see what we learned. I remember carrying around a paper wad with a paper clip gently attached to it for two weeks because my lab partner and I wanted to know if the smooth surface of the metal balls had an effect on how the pendulum swung.

We would swing different weight balls, balls of different materials, different surfaces, etc., change the string length, the height at which we released the ball, the direction we released the ball, every option we could think of, we tried. We learned about potential energy, kinetic energy, velocity, period of oscillation, amplitude, sinusoidal movement and that the only factor affecting the period was the length of the string.

In the history of my education I have never enjoyed or been as motivated or as frustrated by any class like I was by this one. The frustration was a benefit and not a deterrent. Dr. Layman not only made each and everyone of us feel as if we were competent, intelligent scientists, he also helped us to learn to rely on each other, and to respect the ideas of all of the members of the group. He taught us not to be afraid of science, or experiments, and he taught us to be skilled (not perfect, just more skilled) observers of the world of science we live obliviously in.

Figure 3. Example of a reflective journal.

In an interview at the end of her semester of student teaching, Deborah reflected upon what she had learned in the methods course:

> The thing that left the most lasting mark for me was taking all the science-learning-in-progress [journals] and finding commonalties. Even on an individual basis, looking through all my science-learning-in-progress essays, and finding out that "hey there are some

Science learning
Allows Students to
follow their curioustie

water, and made that connection. Another factor was that he is a very curious child,
trying to understand his environment.

What is fostering science learning in this case is an insatiable curiosity, which I 9/20
think most children have (until as adults we finally squelch it).

We need to realize that not every student will focus on the science that is the "focus" of our lesson, and 11/17

In this case I think the cause of the science learning was a child's natural curiosity. 11/18

Although we have a long way to go to answer all of these questions, he is learning. 9/20

He is making lots of observations and asking questions based on a variety of bits and pieces of knowledge he has from prior learnings and experiences. 9/20

we need o encourage them to pursue their curiosities. 11/18

a wide assortment of "junk" that always seems to be on the dining room table, they
natural sense of curiousity. I never said a word 11/13

idea that was a deviation from the original direction of the experiment, Dr. Layman encouraged us to follow that idea and see what we learned. I remember carrying around a paper wad with a paper clip gently attached to it for two weeks because my lab partner and I wanted to know if the smooth surface of the metal balls had an effect on how the pendulum swung.

Figure 4. Example showing claim based upon evidence drawn from reflective journals.

common themes here, there are some real strong messages about why these were positive experiences," And then to listen in class as people shared [their claims] and to find out that most of us had the same ideas about what made those positive experiences, it was eye opening, even though they were things that you really know in your gut but you never actually communicated.
... This also connected for me everything that [my physics professor] did. All the things that I discovered as my common threads were things that [my physics professor] did in his class. My first one was "Science learning takes place with dedicated caring teachers

C. Fostering science learning according to recommendations in part A.

The science conversation I designed fosters all of my claims about science learning in progress. My first claim is that science learning needs to be hand-on. Even though I initiate the lesson asking the group not to touch, later on in the lesson, they are asked to feel the different plates to se if they can feel a difference in temperature. The students have to use the thermometers, and then are asked to bring in things from home to further test their hypothesis. I wonder if they will have the same reaction we did in Physics 117 - we didn't believe the thermometers, we believed our hands!

The second claim is that science learning allows students to follow their curiosities. In this experiment I need to be prepared for some questions that are tangential to come up. For instance, what if a student asks about the ambient temperature of a refrigerator or freezer? Someone might ask if the same theory holds true outside, or on the moon. I need to be prepared to allow them to follow some of these tangents, and to put others aside for future learning or individual investigation.

Real world connections are necessary for science learning is the third claim I have. I think this lesson will make lots of real world connections for children, which is true in almost any circumstance when children are doing things "hands-on." If children don't see the applicability of the situation right away, I need to plan additional activities, or ask more questions to help guide them to the real world connection they need to make.

The last statement I made about science learning is that it needs a dedicated, caring teacher who develop a sense of community in their classrooms. I think this is one of the most important of the claims I have made. One of the most effective learning experiences I had was in a situation where each student was made to feel as if she/he were critical to the groups and the teachers success. We learned to rely, respect and and challenge one another. I am sure that if I can achieve this in the classroom, it will

Figure 5. Excerpt from final in which Deborah discussed how she would meet claims in context of teaching a lesson of her choice.

who take the time to develop a sense of community." One of the comments I have under this is that teachers who are committed to teach and not to transfer knowledge are teachers who make a difference. The next one is "science learning means real-world connections" and "Science learning allows students to follow their curiosities" and this is something I've experienced in classrooms over the past five years, we're always killing a child's curiosity—"not now" "later" "what are you supposed to be doing?" "time's up"—My last one was "science learning needs to be hands on."

Roberts, interview, 6/96

Near the end of her fourth year of teaching, Deborah wrote the following reflection about the long-term influence of her analysis of factors that foster science learning.

Articulating Long-Term Influences of Pedagogical Inquiries (by Deborah Roberts)

For me, the themes I took away from the analysis of my journals have shaped the way I teach. I have copies of these hanging up in my classroom, where I frequently see them. Even without reading each word again, just seeing them serves as an in-depth reminder of my goals. This is a very helpful positive and encouraging symbol for me, because in the trenches of day-to-day teaching it reminds me of the high standards and aspirations I developed for myself as a teacher.

I have had the pleasure of working with three student teachers in my classroom. Two of the three took the same physics course that I had taken. All three have taken Emily's science teaching methods course. All of the student teachers have seen my tattered themes hanging in my classroom. My first student teacher, who is now teaching first grade at the same site, noticed that his methods class expressed some of the same ideas that he saw on my papers. My second student teacher was impressed that I had this information hanging in my classroom. "Wow!" She said, "Look at this! You really took this stuff seriously!" My third student teacher and I actually read some of the notes listed under each theme. She asked questions about some of the comments. Later that day after a science activity, she said, "you have really got science down, Debi!" I'm not so sure that "I've got science down" but I am very thoughtful and intentional about my science instruction. And part of the reason for that is because of the reflective journals (science learning in progress) that we had to keep.

My experiences in keeping a journal have enabled me to become a "reflective practitioner." My definition of this term is this: a reflective practitioner is someone who has a question about something positive that's occurring in the classroom and researches and reflects on that question to better understand one's teaching practice. Reflective research does not attempt to fix a problem but to take an in depth look at something that is going well and to attempt to understand it. At times this results in "fixing a problem" but that is not the focus nor the intent of the research.

I became part of a teacher researcher group during my first year of teaching. Most of the members were first year teachers who had taken Emily's methods course. The Science Inquiry Group or SING as we affectionately call it is a group of teachers from various sites who get together once a month to talk about their science teaching practices, and the research that they are doing in their own classrooms (van Zee, 1998a). This meeting gives us an opportunity to support one another in a way that is not usually done in a normal school setting. We come together and share ideas about science, stories about what is happening in our own classrooms, and solve problems with one another.

In the first year, I chose a topic to research at the beginning of the school year that was so broad and ambiguous that I quickly realized (with the help of my SING colleagues) I would have to modify. I modified it again and again until I finally had a question that was specific enough to try to understand in the context of my own classroom. I was encouraged to present my findings at a "research festival" that Emily had organized and then at a national conference for teacher researchers (Roberts, 1997). The research festival provides an opportunity for Emily's current methods students to talk with teachers from SING about their research projects and to hear about the research that the teachers are doing in their own classrooms (van Zee, 1998a; van Zee, Lay & Roberts, 2000).

The science teaching methods class was taught using the inquiry method of teaching, which we had all been lectured about how to do but very few of us had seen modeled (van Zee, 1998b). Making connections to prior personal learning of science gave us a foundation on which to build. Sharing those connections with our class and noticing the commonalties had a deep influence on me. This class helped me to develop a philosophy of teaching, helped to validate the ideas I had about how to teach, and helped me see myself as able. I had to think critically, reflect on my thinking and teaching, and make difficult decisions. Having to think about my own positive learning experiences in science clarified for me how science learning could be optimized in my classroom. Making these connections has helped me define how I teach science and other content areas as well as how I want my classroom climate to be.

DISCUSSION

This study examined the use of pedagogical inquiries as a basis for learning to teach in a course on methods of teaching science in elementary schools. The prospective teachers' prior knowledge of science pedagogy was elicited on the first day of class by inviting them to draw pictures of positive science learning experiences, to write captions for their pictures, and to identify factors that fostered science learning in these instances. The prospective teachers then constructed joint lists of factors that had fostered their learning such as participating in hands-on activities, generating experiments, and engaging in explorations relevant to their own interests. This is a vision with which prospective elementary school teachers *entered* a course on the methods of teaching science after reflecting upon their own positive science learning experiences. Emily views her primary task as instructor to increase the confidence and competence of the prospective teachers to enact such visions as they enter the teaching profession.

Contribution to the Literature on Reflective Teaching

Much of the literature on reflection has focused on ways to help deepen understanding of difficult situations. Dewey, for example, stated (Dewey, 1993, pp. 100–101; cited in Grimmett & Erickson, 1998, p. 6):

> The function of reflective thought is, therefore, to transform a situation in which there is experienced obscurity, doubt, conflict, disturbance of some sort, into a situation that is clear, coherent, settled, harmonious.

Schön (1983, p. 40; cited in Grimmett & Erickson, 1988, p. 9) described the process of perceiving the problem as inherent in making progress toward its solution:

> When we set the problem, we select what we will treat as the "things" of the situation, we set the boundaries of our attention to it, and we impose upon it a coherence which allows us to say what is wrong and in what directions the situation needs to be changed.

Loughran (1996, p. 14) stated that

> The purpose of reflecting is to untangle a problem, or to make more sense of a puzzling situation; reflection involves working toward a better understanding of the problem and ways of solving it ...

Given the multitude of problems that teachers face, such emphasis on resolving difficulties through reflection seems reasonable.

An alternative view, however, is to focus on positives, to discern as "puzzling" instances of success and to gather and interpret relevant data, perceive and consider alternatives, and devise, test and revise possible courses of action that foster such successes. We believe that this perspective is consistent with aspects of the literature on reflection such as "getting curious about the things kids say and do" (Schön, 1988, p. 20) and "reflection helps the individual to learn from experience because of the meaningful nature of the inquiry into that experience" (Loughran, 1996, p. 14). Our interest has been to engage prospective teachers in inquiring into positive experiences in learning science and building personal frameworks for science teaching on the basis of their analyses. Like Hammer (2000), our intent has been to identify resources for learning, in this case for learning to teach.

Relation of Findings to Approaches Advocated in Reform Documents

As discussed later, the results of this study suggest that prospective teachers entered Emily's course on methods of teaching science with some useful knowledge that could provide a basis for understanding recommendations made in reform documents such as the *National Science Education Standards* (NRC, 1996). Comparison of the prospective teachers' initial knowledge with the standards also suggests, however, areas that likely needed further development. Figure 6 lists the six science teaching standards set forth in the *National Science Education Standards* (NRC, 1996). To what extent are these reflected in the visions of science teaching constructed by the prospective teachers in the Fall 1995 and Fall 2000 classes?

None of the prospective teachers used the term "inquiry" in their captions, individual lists of factors that fostered science learning, or their joint lists. However, their vision of science learning provides a basis for learning how to teach in ways that meet Teaching Standard A of the *National Science Education Standards*, "Teachers of science plan an inquiry-based science program for their students" (NRC, 1996, p. 30). Many of the small groups listed phrases such as "student-generated experiments," "self-discovery," "asking and answering questions," "curiosity," "we all had an opportunity to explore," and "freedom to experiment and test." Note, however, that most prospective teachers drew pictures of experiences such as making a "volcano" or taking a nature walk rather than of student-generated experiments. This suggests that a science teaching methods course can deepen prospective teachers' understanding of inquiry teaching and learning by providing opportunities to formulate questions about natural phenomena and to design ways to answer these.

The prospective teachers' factors that foster science learning also provide a basis for learning how to teach in ways that meet Teaching Standard B of the *National Science Education Standards*, "Teachers of science guide and facilitate learning" (NRC, 1996, p. 32). Several of the prospective teachers' lists mentioned the importance of an enthusiastic teacher who asks good questions and "empowers" students. Both classes also included sharing knowledge through working in collaborative groups as an important factor. Note, however, that few of the drawings depicted students engaged in a vigorous discussion of what they think. A science teaching methods course needs to promote explicitly an image of learning science as learning to engage effectively in argument and explanation.

No prospective teacher mentioned the focus of Teaching Standard C, "ongoing assessment of their teaching and of student learning" (NRC, 1996, p. 37). Apparently none viewed taking tests as a positive science learning experience worthy of articulation. Likely none had had experience with embedded assessments, rubrics, or performance assessment tasks. This is an area that needs to be emphasized in a methods course as the prospective teachers seemed to have had little to build upon in designing assessments that foster science learning.

Teaching Standard D states that "teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science" (NRC, 1996, p. 43). Many of the drawings depicted science learning environments

Teaching Standard A

> Teachers of science plan an inquiry-based science program for their students.

Teacher Standard B:

> Teachers of science guide and facilitate learning science.

Teaching Standard C

> Teachers of science engage in ongoing assessment of their teaching and of student learning.

Teacher Standard D:

> Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science

Teaching Standard E

> Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.

Teaching Standard F

> Teachers of science actively participate in the ongoing planning and development of the school science program.

National Research Council (1996). National Science Education Standards. Washington, D.C.: National Academy Press.

Figure 6. Teaching standards from *National Science Education Standards*.

that had been successfully designed and managed. The drawings represented the use of resources outside of school such as museums and parks as well as some resources inside schools. However, none of the prospective teachers mentioned the importance of having time for a sustained inquiry. In addition, either they did not have access to computers and other complex equipment or did not perceive these to be useful in fostering science learning. This is another area that needs emphasis in courses on methods of teaching science.

Some prospective teachers mentioned factors associated with Teaching Standard E "teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning" (NRC, 1996, p. 46). They commented upon the importance of formulating and pursuing their own questions, of collaborating in groups, and sharing knowledge. Deborah formulated a claim that stated "Science learning takes place with dedicated, caring, teachers who develop sense of community." None of the prospective teachers, however, depicted using intellectual resources of a broader community such as journals and books. Methods courses can introduce prospective teachers to such resources, particularly to literature on student understanding of science concepts.

No prospective teachers mentioned factors associated with Teaching Standard F "teachers of science actively participate in the ongoing planning and development of the school science

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program" (NRC, 1996, p. 51). Likely they were unaware of their teachers' involvement in such activities.

Relation to More Typical Experiences in Learning Science

Many of the prospective teachers commented that the vision created by this process was *not* characteristic of most of their prior experiences. Apparently many had had very negative experiences in science courses, felt anxious about having to teach science, and viewed themselves as uninterested and incompetent in science areas. Forming a positive vision on the first day was a first step toward changing these self-perceptions. The posters demonstrated that all of the prospective already knew something valuable about good science teaching. We hung the posters on the wall in our classroom and along the hall as visual reminders throughout the term of what they knew about ways to foster science learning.

Unfortunately, many of the prospective teachers reported that they rarely saw science teaching in their placement settings or that they saw much more traditional approaches to science teaching than recommended in the standards documents. It would be easy for them to conclude that the methods advocated in their university course were unrealistic and impractical. However, their posters provided evidence from their own experiences that these methods seemed to work when enacted. Forming their own personal frameworks for science teaching may help them to persist in inquiry-based approaches in spite of lack of encouragement or even discouragement from colleagues. Deborah, for example, wrote the following reflection about the influence of forming a personal framework on her teaching (Roberts, 1998, p. 3):

> This discovery of what I considered to be the four essential conditions to foster science learning shaped my philosophy of teaching. All of these conditions had been evident in my physics class and my science teaching methods class. These discoveries also enabled me to do my student teaching according to my philosophy and to withstand criticism from my cooperating teacher and teaching supervisor, neither of whom appeared to have an understanding of inquiry teaching.

As indicated earlier, Deborah provided a receptive environment for the methods students and student teachers placed in her classroom. She also influenced several colleagues in her school to undertake systematic reflection upon their own teaching practices through participation in a teacher research group that met regularly after school (Crutchfield, 1999; Harris, 1999; Roberts, 1999; Roberts & Bentz, 1999). Some of these teachers also served as positive models for Emily's methods students and for student teachers (Bethel, 1999; Kagey, 1999).

Limitations

This study has many limitations. Drawings and written responses cannot provide the detailed insights that likely could be gleaned from a study based on in-depth interviews. The prospective teachers' reflections on positive science learning experiences may be biased toward special events such as field trips; therefore, the apparent absence of opportunities for experimental design and vigorous argumentation may not be an accurate view of their science teachers' instruction. We can not know whether learning situations that typically were not pictured (such as using computers) were missing because they were not valued or because they had not been experienced. Emily intentionally focused only upon perceptions of positive science learning experiences. We believe such a focus to be essential in changing

prospective teachers' attitudes from high anxiety about teaching science to growing confidence. Although negative experiences are sometimes mentioned during small group and whole group discussions, we have chosen not to document nor explore these. We also have traced only one person's development from being a student in the methods course to becoming a highly competent mentor teacher. Many aspects of this development remain to be articulated.

Directions for Future Research

Interviews with prospective teachers entering the course could provide more in-depth information about positive science learning experiences upon which they might build in learning to teach. In particular, one could probe for instances, if any, in which they had generated their own questions and discussed their findings with colleagues. We also could assess the prevalence and value of various categories by providing a list and asking them to indicate which they had experienced and to what extent these experiences had been effective in their learning science. A follow-up study that involves other members of the Fall 1995 class also would be informative. In-depth interviews and classroom observations would provide insights into their current approaches to science teaching. In what ways, if any, have they been able to implement the visions of science teaching that they articulated as methods students on the basis of their analysis of positive experiences in learning science? To what extent do they feel they have been influenced by the many negative experiences in their personal histories and the conventional realities of their schools? What do they remember, if anything, about their science teaching methods course and what, if anything, have they found to be useful? What recommendations do they have for making the science teaching methods course more effective? Also of interest would be further documentation and analysis of interactions among methods students, student teachers, and practicing teachers who have valued and benefited from the reflective processes described here.

Implications

Perusal of drawings of positive science learning experiences convey a consistent message—students enjoy learning science when they are actively involved in doing and thinking, in everyday contexts, with opportunities for initiating their own explorations. Developers of curriculum need to consider the long-term impact of their designs, are they creating memorable activities that might be included in reflections of positive learning experiences? Do their designs include opportunities for engaging in argument and explanation? Will their designs enable teachers to enjoy learning science themselves as well as in teaching their students?

Knowledge about prospective teachers' prior experiences in learning science is useful for teacher educators who design and teach courses on methods of teaching science. Such knowledge can guide planning instruction about science pedagogy just as knowledge about common student ideas about the natural world is useful in planning instruction about science principles. Teacher educators need to recognize that prospective teachers enter science teaching methods courses with useful knowledge that can provide a sound basis for learning how to teach in ways that meet the recommendations made in reform documents. Activities in methods courses should be designed to help prospective teachers expand these areas of competence as their confidence grows.

Reform is likely to occur slowly, through incremental efforts such as those recorded here. A physics department devoted resources to developing an appropriate course for future elementary school teachers. A college of education encouraged a faculty member to practice what the standards preach. A student who understood and valued these approaches is now a practicing teacher leading colleagues in her school toward more reflective practices. Together she and her colleagues are forming a culture that welcomes prospective teachers into learning environments that model reform approaches to teaching and learning.

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