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ABSTRACT

Recent science education reforms have advocated inquiry-based instruction in which teachers engage students in scientific investigations and problem-solving situations as an important strategy. This study describes the background and beliefs of a preservice teacher who appears above average in her ability to create and carry out inquiry-based instruction. The study also explores the changes this teacher undergoes in her thinking and teaching as she encounters obstacles throughout the course of a year. Implications for teacher education programs are suggested, including the need to engage preservice teachers in an ongoing endeavor to focus on inquiry in teaching. Using a case study approach, this research simultaneously examines a preservice teacher's planning and the reasons behind her planning, her interaction with students, reflections before and after lessons, and her reflections the year following her one year of field experience. (Contains 41 references.) (CCM)

Teaching through Inquiry: A Novice Teacher's Authority of Experience

by
Barbara A. Crawford

TEACHING THROUGH INQUIRY: A NOVICE TEACHER'S AUTHORITY OF EXPERIENCE

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Inquiry-based instruction in which teachers engage students in scientific investigations and problem-solving surfaces as an important strategy advocated by recent science education reforms (AAAS, 1993; NRC, 1996). Knowledge of inquiry is also a key outcome for students as stated in the National Science Education Standards -- "the ability to conduct inquiry and develop an understanding about scientific inquiry" (NRC, 1996, p.105). State frameworks promote students' construction of scientific knowledge through processes such as developing questions, empirically testing hypotheses, and gathering and synthesizing information (e.g. State of Michigan Department of Education, 1993).

These reform-minded orientations to teaching inquiry build on a research base of constructivist views of learning (Brown, Collins, & Duguid, 1989; Cobb, 1994; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Newman, Griffin, & Cole 1989). The reforms explicitly ask teachers to change their teaching by shifting the emphasis from the textbook to exploring questions that are student-centered and can be answered empirically. Teaching Standard B of the Standards states that teachers "focus and support inquiries while interacting with students" and that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (NRC, 1996, p.32-33). In addition, the Standards advocate that teachers

design investigations situated in real phenomena, in classrooms, outdoors, or in laboratory settings and that are demanding, yet feasible for students to carry out.

However, orchestrating this kind of instruction is not a simple endeavor. Inquiry-based instruction challenges the most expert of teachers (Gallagher, 1989; Krajcik et al., 1994; Marx et al, 1994; Tobin, et al., 1990). Challenges to create this kind of instruction escalate in the case of novice teachers who have the liability of inexperience in several domains of knowledge of teaching including pedagogy, pedagogical content knowledge, knowledge of students, and knowledge of classrooms (Shulman, 1986). This study is important because it helps fill the gap in understanding how the intended curriculum of the reforms links to classroom practice of beginning teachers. This study describes the background and beliefs of a preservice teacher who appears above average in her ability to create and carry out inquiry-based instruction. Further, this study explores the changes this preservice teacher undergoes in her thinking and teaching as she encounters obstacles throughout the course of a year. Finally, implications for teacher education programs are suggested including the need to engage preservice teachers in an ongoing endeavor to focus on inquiry in teaching. Using a case study approach (Yin, 1989), this research simultaneously examines a preservice teacher's planning and the reasons behind her planning, her interactions with her students, her reflections before and after lessons, and her reflections the year following her one year of field experience.

Visions of the kinds of learning environments set forth in reform documents portray the outcomes, but leave out details of day-to day-events in the real world of classroom life. Because this kind of teaching demands that teachers build on students' current states of knowledge, one might question the ability of preservice teachers to successfully carry out this kind of instruction. Given that preservice teachers have to deal with all the complexities of the classroom as novices, this study focused on the central question: *In what ways is it possible for a preservice teacher to successfully construct an inquiry-based learning environment?*

This study consisted of an in-depth collaborative study of one preservice teacher's endeavors to design and carry out two inquiry-based units over the course of her one year field experience. Questions relating directly to this preservice teacher's work included:

1) In what ways did this preservice teacher engage her students in inquiry?

2) What factors contributed to this preservice teacher's decision to design and carry out inquiry-driven instruction?

3) What were the supports and constraints to this preservice teacher using inquiry?

4) What implications do these findings have for other preservice teachers?

Theoretical Framework

Inquiry-based instruction involves students pursuing the answers to significant questions (Brown & Campione, 1990) in ways similar to those used by scientists (Brown et al., 1989). Inquiry should not be confused with merely providing students with a series of hands-on activities. Instead, teachers need to meld inquiry activities with constructivist-oriented discussions to facilitate students building on their current knowledge and revising their understandings (Driver, Asoko, Leach, Mortimer, & Scott, 1994). This study is influenced by social-constructivist theories in which students' understandings of science are actively built in a social setting through a process of debating and negotiating with others (Solomon, 1989; Vygotsky, 1978; Wood, Cobb, & Yackel, 1992). Interactions of the students and teacher are the foci of the tugging and pushing of ideas students bring to each lesson.

Having students solve problems and do "real" science stems from the writings of John Dewey. Dewey believed that children learn from activity, through a continuum of their own experiences, and from contemplating the writings of others (Dewey, 1938). A number of researchers have applied Deweyian ideas of experiential learning to classroom-based projects and long-term investigations that are student-centered and contextualized (Krajcik et al. 1994; Roth, 1994; Roup, 1993; Schwab, 1976; Tinker, 1991). Authentic problems that students solve collaboratively differ from traditional school science "experiments" that tend to be verification labs during which students seek the "right" answer. Instead of completing exercises from a

chapter in the textbook, students construct their understandings by solving real-world problems (Tinker, 1991).

This study focuses on the feasibility of a preservice teacher to immerse students in the kind of experiential learning that includes both social-construction of knowledge and contexualized instruction. Preservice teachers in fifth-year programs typically enter with varied experiences and orientations to teaching and learning science. Likewise, teacher education programs vary in the extent to which ideas such as the nature of science and inquiry-orientations to pedagogy are explicitly addressed in methods courses. For example, one study of an elementary preservice science cohort found that challenges and difficulties associated with designing and carrying out instruction include linking concepts, assessing students' prior knowledge, and improvising during instruction (Starr, Zembal-Saul, & Krajcik, 1997). The ability to adapt and mold instruction in response to student-centered inquiry appears a likely stumbling block for novice teachers who have difficulty with improvisation during interactive teaching. Researchers point to the need for novices to develop an integrated understanding of pedagogical content knowledge that includes the ability to transform the essence of subject matter into an understandable form (Grossman, 1991; Shulman, 1986). In this study Inquiry is the subject matter to be transformed.

Background of the Preservice Teacher

The study of Denise, the preservice teacher in this study, evolved during the fall term of 1995. Denise, a pseudonym, was one of 22 cohort students in the twelve-month, fifth year Masters in

Arts in Teaching (MAT) program at a northwestern university, 14 of whom majored in science education and the others in mathematics education. After beginning the MAT program in the summer, Denise was placed for her fall practicum field work. Her high school placement was in a small farming and logging town in the pacific northwest, nestled near the coastal mountains. During this practicum, it became apparent to the author, who was her university supervisor, that Denise was unique in her planning. Unlike the other MAT students' traditional units that centered on topics, Denise planned for her general biology students to study nutrient cycling through a collaborative, aquaculture/hydroponics project.

Prior to entering the MAT program, Denise had varied work experiences in horticulture research and as a volunteer teacher's aide. Denise worked for ten years in commercial and university labs, conducting studies such as screening for bacterial isolates and running experiments relating to weed control for local growers. As part of her job responsibilities she wrote proposals, designed and carried out a variety of experiments, and gave oral presentations. In order to strengthen her application for the MAT program, Denise volunteered to work with teachers in two different schools. Denise assisted Jake, a high school teacher regarded in the community as an excellent teacher who involved his students in community-based projects. Denise also worked with Linda, who later became her mentor teacher. With the backdrop of her varied life experiences, Denise became an expert informant on the thinking of a beginning teacher.

School and Community

The small public high school of approximately 120 students was a center for activities in the small town, and the local community enthusiastically supported the football and basketball teams. The high school faculty shared course expectations and background information on students. Teachers had significant input in the development of the district curriculum, and had flexibility in designing instruction. Denise's mentor teacher had graduated from the MAT program five years before, and her activity-based classroom was stuffed with aquaria, books, lab materials, and student work.

Although the twenty students (14 boys and 6 girls) in the sophomore biology class were not culturally diverse, the students ranged greatly in academic success and ability. One student had certified learning disabilities, several students publicly contemplated dropping out of high school as soon as they turned sixteen, and another student was a young mother and frequently absent.

Overview of the Two Inquiry-based Units

Denise successfully designed and taught two inquiry-based units for the sophomore biology class: the first, she called Nutrient Cycling, included a collaborative project in which students worked in groups as they designed and conducted an experiment associated with a Aquaculture/Hydroponics system. The second unit, taught in the winter term, Denise called the

Independent Research Project (IRP). Denise described the IRP as a more involved project in which each student chose an area of interest, developed a feasible research question, reviewed current literature, designed and conducted an empirical investigation, drew conclusions from the investigation, wrote a technical report, and made a formal presentation to the class. During the winter term, Denise designed a global warming unit for two eighth grade integrated math and science classes which was not part of this study. However, Denise's decision to plan this additional project-oriented unit provided further evidence for her orientation towards projects and inquiry-based teaching.

Method

The purpose of this study was to document Denise's field experience in order to characterize her planning and classroom teaching, and to determine the factors influencing her decisions.

Sources of Data

The case study of Denise's planning and instruction developed from multiple sources of data representing perspectives of the author (serving as fall supervisor), a second university supervisor (for the winter term), the mentor teacher, the students in Denise's class, and Denise. The research relied heavily on input from Denise, the teacher, and focused on understanding how Denise made sense of her teaching (Richardson, 1994). The main sources of data involved

actual classroom observations to verify how Denise carried out her plans. Denise acknowledged the most important influence on her learning to teach was her field work, the student teaching experience. Records of Denise's teaching during the fall term included the author's written observations of lessons once a week During this time, the author's role was that of Denise's university supervisor, and the formal written observations included critiques of the lessons and suggestions. During the winter term a different university supervisor recorded observations of lessons once a week. The author continued to make weekly classroom visits throughout the winter term and compiled handwritten and videotaped records of each of Denise's lessons.

Another important source of data included audiotaped conversations between the author and Denise. Conversations took place throughout the fall and winter terms, during the following summer, and during the fall of Denise's first year of teaching. These conversations consisted of two kinds: 1) semi-structured interviews guided by protocol questions designed by the author lasting 30-45 minutes and centering on lesson planning issues, post-lesson debriefing, and the research questions; and 2) informal conversations occurring weekly during fall and winter and continuing into summer and fall of the second year, ranging from a few minutes to 30 minutes or longer. These informal conversations allowed Denise to talk freely about her thoughts centering on day to day events in the classroom, challenges she encountered, and revisions she made in planning. As a first year teacher, Denise described her new challenges and successes and reflected on lessons learned from her preservice teaching experience.

Additional data sources included a) written observations by the mentor teacher and a second university supervisor during the winter term; b) Denise's written lesson plans and formal written reflections; c) videotaped interviews of pairs of students in early April to determine student's perspectives of the second unit (Denise suggested that students be interviewed in pairs to create a more comfortable environment); d) students' final written reports for both units; and e) audiotaped conversations with the second university supervisor.

Analyses of the Data

Analysis of the videotaped lessons followed an interactive process described in previous studies of inquiry-based instruction (see Crawford, 1996 ; Krajcik, et al., 1994). This interactive process utilized a three part scheme consisting of data reduction, data display, and conclusion drawing and verification (Miles & Huberman, 1994.) Documents were produced by first writing summaries of each lesson segment--a segment consisting of a change in activity Evidence of students and teacher engaging in inquiry-related events or conversations were noted, and these sections were transcribed. Commentary was then written following each segment, noting teacher and student interactions. Finally, hypotheses were written guided by the research questions. This process produced a narrative document for each videotaped lesson.

These narrative documents along with documents from the other data sources described below were placed in chronological order and formed the base for finding patterns in Denise's teaching and beliefs. Placing the documents in chronological order served to highlight changes

in Denise's planning and instruction. Each of the data sources were used to either corroborate or refute developing patterns and themes as these emerged from the analysis of the data.

Analyses of the supervisors' and mentor teacher's written critiques of Denise's lessons focused on the summaries of the lessons, descriptions of Denise's strategies, and notations of student responses. After reading through the supervision critiques several times, the author added commentary related to the presence or absence of inquiry-related events. These commentaries were then added to the chronological collection of analyses documents..

Transcriptions were produced of the audiotaped conversations between the author and Denise and the videotaped interviews of pairs of students at the end of the second term. These transcriptions were combined with student reports and students' written responses to a questionnaire given towards the end of the second unit. These documents, combined with Denise's lesson plans, Denise's written reflections after teaching each lesson, and Denise's written philosophy and analysis of her own teaching were used to determine Denise's perspectives on her planning and teaching. The author read and reread each of these data sources and underlined sections related to the research questions. All documents were folded into the chronological collection. Throughout the data analysis the author constructed the case study by writing hypotheses in the form of narratives and then supported or refuted these hypotheses by using each data source (Yin, 1989).

Results

The findings of this study will be organized around the research questions beginning with a discussion of Denise's beliefs about science and her stated goals for teaching.

Denise's Beliefs about Science and Goals for Teaching

In the beginning of Denise's practicum experience Denise utilized language that resembled the kinds of traditional jargon found in documents advocating inquiry. But, by the end of April, Denise had modified her goals to embody a more mature view of teaching inquiry. In the fall Denise viewed science as "a study of inquiry and the natural world...it is important I believe that we teach science as an ever growing and expanding field of study; where creative new ideas and interpretations may lead to new knowledge; where ideas are open to consideration and scrutiny; where new theories continually redefine how we view the world, and ourselves" (from her written Philosophy of Education, crafted during fall coursework).

Denise's initial goals for teaching centered on getting students to think, communicate, and take responsibility. One of Denise's primary goals for teaching was for her students to learn to think independently and to critically evaluate information given them. Denise viewed her role as a facilitator and "the role of education is to guide students through this development and encourage problem-solving skills, effective communication, critical and creative thinking, focus, and a sense of local and global community ownership" (from her written Philosophy of

Education, revised Feb. 1996). By the end of February, Denise attributed her success in student teaching to instruction "centered around student projects (both independent and cooperative) that involved a variety of applications in math, communications, and discussion of social issues."

By the end of April Denise had modified her goals to include aspects of student performance based on the realities of classroom experience. This modification resulted from Denise's reflection on students' work during the fall Nutrient Cycling unit and the winter IRP unit. Denise experienced frustration in the fall when some of the students failed to contribute to the group investigations. Denise noted that in almost every group, all the work was done by one or two students. In the winter, Denise changed from cooperative group work to individual research reports. By the end of the winter term , a few students still failed to complete a final written report. Thus, a goal that emerged for Denise based on her fall and winter experiences targeted students acquiring the values of self-motivation, challenge and success. In the year following her preservice field work Denise continued to express her goal that students take initiative and develop ownership in their learning.

In interviews over the year of her preservice experience, Denise restated her concern with clarity and relevancy as illustrated by her responses to questions about her teaching. When asked what she thought was important in her teaching, Denise responded, "That's a wide open question.." When pressed to continue her response, she identified "Clarity.. relevance. (pause)... sincerity.. honesty." When asked to identify what was important in learning, Denise responded,

"Relevance, I suppose. That's the top of my list." She later added that communication was extremely hard for her. "It is a real learning process. It is so straightforward, and yet being able to understand, the knowledge base, a basic conceptualization.. some of the kids.. it seems linear, like putting variables into equations. I'm not sure. Again, there's just a big communication problem." Although Denise articulated some fairly clear goals such as making instruction relevant to students, other ideas appeared to be still in a formative stage of development. Denise appeared to struggle with the process of communicating her goals to her students.

In What Ways Did this Preservice Teacher Engage Her Students in Inquiry?

Denise designed inquiry-based experiences beyond that of a typical MAT student during both the fall and winter terms. The fall unit engaged students in designing and carrying out experiments relevant to people living in an agricultural community. In the winter Denise's students selected questions that related to their own interests and conducted independent investigations. Denise excelled when working with small groups or one-on-one with students on independent investigations. Yet, Denise struggled when carrying on whole class discussions focused on students developing their understandings of science concepts. Thus, Denise's instruction was characterized as dichotomous-- often she began her lesson with a teacher-directed lecture targeting terminology, and ended her lesson using an inductive, inquiry-based approach as students worked on aspects of investigations.

Design and Teaching the Fall Unit-- Nutrient Cycling

Features of Denise's teaching during the fall unit included: 1) teacher facilitated, question-driven investigations related to nutrient cycling; 2) effective mentoring of students in small groups and individually; 3) struggling with motivating all students to contribute to group work; 4) dichotomous lessons using two contrasting methods; 5) lecture parts of lessons targeting terminology.

The MAT program required students to design and teach a three week unit during the fall practicum experience which represented for most of the preservice teachers their first extended teaching experience. The formal write-up of this unit called a Work Sample, included the Rationale, Unit Goals and Objectives, Lesson Objectives and Detailed Plans, Written Reflections, Student Data Analysis of Learning, and Analysis of Teaching. The work sample consisted of a hefty document composed of numerous topic papers, revised lesson plans, calendar of lessons, examples of student work, tests, and additional resources. Although most of the MAT students developed units around traditional topics found in the biology textbook such as cells, classification, and genetics, Denise created an original project-driven unit. In this project students designed and carried out aquaculture/hydroponics experiments while learning about the role biotic factors play in the balance of cycling. Denise wrote in Work Sample #1 that "the first goal is to initiate students to the concept of nutrient cycling by drawing on familiar knowledge of oxygen and carbon dioxide exchange in photosynthesis and respiration. An

additional goal of this unit is to give students an opportunity to design their own experiments and explore the parameters involved in a scientific inquiry." Denise planned and taught the Nutrient Cycling unit in eight sequential, 85 minute lessons from mid-October to mid-November.

As an example of innovative instruction during the fall, Denise developed an inquiry-based lab of her own creation that involved students testing nitrogen levels in horse manure and barn shavings. During part of the investigation students followed procedures for extracting nitrogen from both aged and fresh manure, carefully recorded data, drew conclusions, and discussed sources of error. The inquiry was contextualized and afforded students opportunity to collaborate about problems related to the real-world of a farming community. For example, the homework question asked, "Do your results give you indications as to why fresh manure might injure plants?"

During the lab work time Deb moved easily from one student to the next, interacting by asking questions and answering questions with thoughtful responses. All the students actively conducted tests on the two manure samples, and collaborated about their observations. During the debriefing Denise emphasized the critical components of an experimental design including development of an hypothesis, identifying independent and dependent variables, and the importance of constants. Denise later reflected on Lesson #2 in her writing:

> Introducing nitrogen into the lesson went well but would (in re-teaching) require modifications for better clarity and focus. The responses to the nitrogen questions asked in class discussion were great. Many of the students knew that fresh manure causes plant injury (smelled significantly stronger of ammonia than aged manure) and that kitchen compost was not as good of a nitrogen source as manure for garden plants. Additionally there were some interesting questions from students about mushroom growth and mature relationships, effects of burying manure, and how manure differed with different animals.
>
> (Lesson Reflection, 10/19/95)

Denise continued to engage her students in inquiry as she introduced the centerpiece of the Nutrient Cycling unit: "Think of a question that would be interesting to test that utilizes an Aquaculture/Hydroponics system". Student ideas brought to the next class session sparked a good discussion about possible experiments. Denise assigned students to small groups, and gave roles to different students. Denise guided her students in designing their experiments by teaching them the 4-Question-Step Process (Cothron, et al., 1989). This process created a framework for her students relating to selecting materials, treatments, and measuring responses.

Denise's assessment rubric gave the highest points to students who clearly identified the independent and dependent variables, were able to write a clear support for the hypothesis, developed treatment that exhibited a good understanding for nutrient cycles, sampled carefully

throughout the experiment, clearly presented the results of the project, and worked well in their group.

For their investigations, groups set up one gallon jars and varied numbers of fish or amounts of plants to see the effect on other parts of the system. For example, one group wrote:

> "Our group wanted to find out the effect of plant density on plant growth. We thought that the more plants in a tank there were, the more fish would be needed to balance the pH, nitrite, nitrate, and ammonia. The hypothesis stated: The density of cutting will affect the rate of rooting of Wandering Jew."

During group inquires Denise perceived her students to be motivated and that "overall I felt the Ss enjoyed this lesson, most were actively engaged throughout" (Lesson Reflection Day 5). Minor challenges included supporting students in data collection and refocusing a few students who strayed off-task during open work times.

Major challenges that influenced Denise's design of her second inquiry-based unit included missing an opportunity to integrate more writing into the final product, and the imbalance of effort by different members of the groups. Denise wrote, "What happened in several groups, only 1 or 2 people worked really hard to complete the comprehensive report, while their group members did literally none of the final report or presentation work." (Lesson Reflection Day 6).

Although Denise created inquiry-based opportunities for her students beyond the typical MAT student, many of Denise's lessons were dichotomous as described earlier; half of the

lesson consisted of information-dispensing segments and the other half, were inquiry-based centering on innovative activities. During the first half of these lessons Denise focused primarily on presenting information: carbon dioxide and oxygen cycling, flow of forms of nitrogen through an ecosystem, description of Aquaculture and Hydroponics systems, and how to design and set up a controlled experiment. Underlying these teacher-directed parts of her instruction was Denise's concern with *clarity*, a theme that emerged over the course of the year.

Denise's concern with clarity may have related to her focus on terminology. Denise's lecture-style parts of lessons targeted terminology, and had limited success in engaging students in grappling with conceptual understandings. During these lesson segments, Denise usually stood at the front of the room using the overhead projector to define terms or show complex diagrams such as nutrient cycling.

One lesson in mid-October illustrates how segments within the same lesson could differ greatly in the opportunity for inquiry, student input, and knowledge construction. During the first part of the lesson Denise disseminated information relating to a lab on manure (Lesson #2, 10/19/95). Denise wrote the formula, N (triple bond) N on the overhead while saying the word, "nitrogen", followed by giving the quantity of N in the atmosphere. One boy asked about the triple bond, but Denise responded that would take her a week to explain. As Denise began to fill the overhead with chemical formulas and explained the role of bacteria in the nitrogen cycle, the students watched passively without asking further questions. During the second half of the

lesson, Denise engaged her students in testing nitrogen levels in horse manure and barn shavings manure in a lab described above.

In her written reflection, Denise recognized that she needed to modify the lesson to introduce the nitrogen molecules a little more simply. In addition she needed to cut down the presentation of the entire nitrogen cycling to information pertinent to that lesson. Denise recognized that the molecular chemistry part of the lecture confused her students, and decided she needed to introduce concepts on a "as-needed" basis.

Denise's final reflections on the entire Nutrient Cycling unit highlighted her ownership of the unit and enthusiasm for revising and re-teaching it. In addition she noted that her students had gained ownership of their own experiments. "The projects were the most motivating part of the unit for almost all the students, even those that often remain relatively uninvolved." (Summative Evaluation of Student Teaching, Dec., 1995). In interviews, Denise articulated two concerns. First, Denise struggled with clarity. Denise recognized that she had confused students with vocabulary to which they did not relate. Second, Denise identified the poor dynamics between some group members. Denise identified that this lack of cooperation hindered group members' full potential.

Design and Teaching the Winter Unit- The Independent Research Project (IRP)

During the winter Denise continued to build on her success using inquiry-based instruction, and incorporated modifications in the design of her instruction based on her reflections on the

fall. Denise envisioned her students choosing a question based on their own interests, using the literature as a base on which to build, designing an original, controlled experiment, and finally writing up a formal report. For their final IRP product Denise expected her students to produce a five to six page biology research including an impact statement to connect the results to issues relevant to the world.

One big change from the fall unit to the winter unit, was that Denise taught the IRP "wedged in between" lessons on cell biology and bacteria and viruses. After reading the author's draft of her own case study Denise crossed out the words "integrated in her subject matter lessons". As a correction, Denise wrote in the margin, "IRP- concurrent with regular subject matter required in general biology." In other words, the IRP was a discrete unit from the cell biology unit, although they ran parallel to each other. The IRP lessons spanned from January 18 to the final student presentations in late March, the week that followed the school spring break. Denise's calendar of events portrayed an initial lesson on the nature of science followed by an introduction to the project. Later lessons alternated discussions of cell organelles and bacteria with lessons directly related to the IRP such as experimental design, use of spreadsheets, and how to create a bibliography.

This second inquiry-based unit presented new challenges for Denise. The first challenge involved Denise' difficulties in guiding students in choosing a topic. The fall Nutrient Cycling project offered fairly limited choices to her students. However, Denise designed the IRP to be

more open-ended and emphasized technical writing. During an interview in mid-February Denise told the story of one interaction: "One kid, he was very obstinate. He.. he wouldn't come up with a topic. ah. And.. well there were a few of them that weren't able to come up with a topic and I was able to guide them in their interests. I would say, what do you think of the world? And there was this one boy. And he finally came up with a topic.of feeding studies of alligators.(laughing) but I wasn't sure how he could get an alligator. I asked if he had snakes at home. No. he doesn't have any .. so. that is where it's at right now."

Once her students selected a topic of interest, Denise guided her students toward selecting a question to investigate and in designing a study using the same 4-Question-Step Process used in the Nutrient Cycling unit. A few students developed experiments related to the fall Nutrient Cycling project. Most of the students investigated completely new topics. Examples of students' questions included: Will small quantities of cotton remove large quantities of oil from the sea? What do teenagers think and understand about abortion? When do Labrador Retrievers begin to experience symptoms of Hip Dysplasia? Which color of light is most important for radish growth? Do mushrooms grow better on cedar or straw substrate? Do bass and trout act differently in different temperatures. Many of the questions explored by students closely matched their own interests, such as breeding Labrador Retrievers.

Denise's lessons continued to follow the dichotomous pattern of the fall lessons, alternating lecture-style segments with inquiry-oriented segments. In early March, Denise lectured on bacteria while students listened passively, asking few questions:

T: Eubacteria. Archeobacteria. I'm not quite sure how you say that.

Does anybody know "holophile"?

Denise, without waiting, proceeded to give the meanings of the two parts of the word.. halo-salt and phile means liking, answering her own question while writing words on the overhead.

T: What is the difference between eukaryotic and prokayotic?

One student responded and Denise completed the student's answer.

T: A nuclear membrane.

On the one hand these lecture-style segments remained teacher-directed and focused on content.. As her winter supervisor stated, "lecture was reduced to terminology." One of her students wrote on a student response sheet that "you used some words and explained things without relating to what we would understand." On the other hand, Denise's interactions with students during project work time exemplified constructivist approaches in her pressing students in thinking about their experimental designs. For example, during project work time in mid-March, students

worked in different areas of the room. Denise moved from one student to the next, offering advice or asking questions as illustrated in this lesson vignette:

One boy working at the back of the room on an aquaculture/hydroponics experiment lamented that his goldfish had died. Denise asked him if he wanted to modify the experiment.

D: Did they die before? Maybe you should use your experiment to test why the fish died.

Denise suggested that he take some ammonia and nitrite readings right then. Meanwhile, another boy arranged samples of radish plants taken from light boxes on a piece of paper. He planned to photograph the slender young plants.. Denise suggested he use colored paper for better contrast. A third boy testing the effect of pasteurizing straw on growing oyster mushrooms wondered about cutting the plastic bags once the mushrooms got large enough. Later, the boy testing the dead fish water, walked over to Denise who was working with another boy using a spreadsheet.

S: "That's a bummer, the nitrite level was high". Look at this concentration of nitrite!"

D: Ah! Now we know what is happening.

Denise explained to the boy how the nitrogen cycle tied in.

D: You could do a nice write-up of your experiment and tell what has happened. That is totally acceptable.

(Lesson 3/16/96)

During project work-time, Denise viewed her role as facilitator and guide. Although the frequent flow of visitors into and out of the room sometimes distracted students (for example, taking pizza orders for lunch) , Denise managed to stay focused on each student as she worked with him or her. Denise's shift from a teacher-centered lecture mode to a more student-centered inquiry mode fit with Denise's recognition of the importance of open-inquiry: "Using their questions as a starting base for research topics was fun, and I feel that it allowed them to feel more ownership over the project."

Students viewed these project times as productive as evidenced by these representative responses to a written survey

Q: What were your favorite parts of this class?

A: When we had work time to work on our projects and experiments.

Q: In what ways did I (the teacher) help you learn?

A: 'Told me some stuff I didn't already know. Gave me ideas for new projects. Helped learn to recognize some deficiencies.

You tried to answer all the questions we had; you showed me better ways to show and interpret data and go about experimenting.

Q: What were your least favorite parts?

A: The worksheets, and there wasn't enough conversation; long lectures about scientific things I'm not interested in.

Student interviews corroborated the students' positive written responses about project work. "She just helped me if I didn't , like sometimes, I'd just get stuck and didn't know what to do and she'd help me figure out what to do next." Most of the students valued the IRP. "It was something that you really wanted to do. It's not the same if someone else comes up with the question because they're not, you know, it's basically not the same, like what people will answer -- if it's not your question... It's your choice (in the IRP), your answer. "

In addition to students exhibiting positive attitudes towards the project work and their teacher, students learned about the importance of variables in designing experiments. When asked to identify some of the problems in doing the experiment, this was a typical response: "I'd have more treatments, and I'd make sure when I boiled the substrates, that they both got to the same temperature, and I boiled them the same amount of time, so it would be the same."

Summary of the two units. Denise engaged her biology students in a variety of inquiry-based experiences. Although not always successful in orchestrating whole-class discussions centered on conceptual understandings, Denise was effective in engaging her students in creative, open-ended, relevant investigations and successfully worked with students in small group settings. Denise wrote in a reflection: "The most powerful lesson for both the students

and myself was the recognition of the value of challenging students to take initiative, ownership, and responsibility for an independent project." Ownership taken by Denise's students during the two projects parallels reports of experienced teachers designing long-term, student-centered project-based instruction (Crawford, 1996; Roth, 1995; Roup et al. 1993; Scott, 1994; Warren, Rosebery, & Conant, 1989). During her field work experience, Denise's planning and instruction correlated with the Standards call for teachers to fashion investigations that are demanding for students, but within their capabilities.

What Factors Contributed to this Preservice Teacher's Decision to Design and Carry out Inquiry-driven Instruction?

Denise's decision to design two inquiry-driven units appeared to stem primarily from her earlier work experiences in labs and field work. This finding is consistent with previous studies that demonstrate the influence of preservice teachers' prior work on the development of their science schema and extending this to their teaching (Palmquist & Finley, 1997.) Secondary influences appeared to be Denise's mentor teacher's reception to her ideas and Denise's experience as a teacher's aide in a project-oriented classroom prior to entering the MAT program.

During a conversation a year after her student teaching, the author asked Denise directly what was the main reason she tried these projects. She quickly said, "Oh, that's easy. My 10

years as a research technician." Denise went on to say that she had been good at designing these kinds of experiments, and had wanted to involve her students in these same kinds of experiences. In a later interview she revealed that the idea for the Aquaculture/Hydroponics experiment resulted from information from a journal as she prepared a "resource card' for one of her summer MAT courses. Contributing to Denise's final decision to develop both the Nutrient Cycling unit and the IRP was her mentor teacher's support and willingness to allow her to try out new things.. "I asked her (my mentor teacher) what she thought about nutrient cycling, and she thought that would be great. So I thought that would be a good way to go about nutrient cycling, and to do an independent research project. So that was an opportunity to try out cooperative group work. I am certain that I got the idea for cooperative group work from the fall (methods) course; that I would not have thought up on my own."

Denise's decision to design the Independent Research Project during the second term appeared to originate from herself and resulted from confidence gained from completing her first project in the fall. When Denise realized that the school curriculum required sophomores to prepare a research paper, Denise quickly saw an opportunity to combine her goals for involving her students both in inquiry and in the writing of a technical paper. Denise stated. "I had that in my head before I even went into teaching..that I would have kids do independent research projects or a group research project. It seems like a natural thing."

Denise's initiative to design and carry out this complex form of instruction resulted from her expertise and confidence in conducting controlled experiments. In addition, Denise had a model of how she could translate her professional experience into her classroom constructed from her volunteer experience with Jake, a project-oriented teacher. Denise acknowledged that "Jake is dynamic, and I would like to spend more time with him in his classroom."

What Were the Supports and Constraints to this Preservice Teacher's Teaching Using Inquiry?

Supports

Once Denise decided to design the inquiry-directed units, several factors influenced her success. From triangulating the data gathered from supervisors, the mentor teacher, and the preservice teacher, six key factors appeared to support Denise in her efforts to sustain an inquiry-based environment. These factors included: 1) prior research experience; 2) volunteering in project-oriented classrooms; 3) extensive planning and having a clear vision of her unit goals; 4) developing a trust relationship with her mentor teacher; 5) collaboration with experts outside the classroom, and 6) consistent and thoughtful reflection on practice.

The first two of these influences on Denise's vision of inquiry-based teaching related to her experiences prior to entering the MAT program. These influences included her experience as a research technician as described earlier, and her experience as a teacher's aide working with

project-oriented teachers. The teaching practices of successful inquiry-based teachers emerged as a model for Denise. "the two people I spent the most time with were Jake and Linda (later, to become her mentor teacher), and they are both project oriented people. ah....and I think it is easier. It is more comfortable and it is easier. (Conversation, 10/19/96)

Third, Denise had a clear understanding of the goals and objectives for both her units and visualized the outcomes she hoped her students would attain. Denise carefully planned both the Nutrient Cycling group project and the more ambitious IRP that included a formal, technical research paper. Although Denise encountered struggles with her students in the journey towards these outcomes, she maintained a clear vision of the final destination. Denise invested substantial time in preparing lessons and materials needed for the unit. Denise's own enthusiasm for the units carried her through days during the second unit when some students resisted, parents challenged her expectations of her students, floods ravaged the valley, and almost the entire school took a week off for a high school basketball tournament.

A fourth factor that sustained Denise was her close working relationship with her mentor teacher. Her winter supervisor stated that "she feels comfortable with calling her mentor teacher....Her relationship with Linda has a sense of trust." The mentor teacher took a maternity leave for part of the winter term. Since the mentor teacher lived in town and Denise felt comfortable with her, Denise would often drop in to talk with her. Due to this established trust between the mentor teacher and Denise, this preservice teacher was given flexibility in choosing

the unit to develop in the fall, as well as the winter. Denise described this freedom as being able to "do anything I wanted." Support from her mentor teacher, flexibility in her choice of units, and encouragement by her university supervisor appeared to be critical to both her initiation and carrying out of the two inquiry-based units.

A fifth factor in supporting Denise was the help she obtained from experts outside the classroom. Setting up the elaborate aquaculture/hydroponics system of aeration required after school time and week-end work. Denise sought out and relied on the expertise of her mentor teacher's husband, who was an aquarist and fisheries biologist. Other resource people important in acquiring materials for her project included a local pet store owner.

A sixth factor that contributed to Denise's resolve to engage her students in challenging inquiry-directed instruction was her thoughtful reflection on her developing practice. For example, when the author first proposed the idea of developing a case study of her teaching, Denise expressed a real interest in looking more in-depth into her own teaching. Her winter supervisor described Denise as "honest with herself and good at reflection."

Constraints

Although Denise experienced success in engaging most of her students in inquiry, Denise also experienced frustration. During the fall inquiry-based unit, Denise was generally concerned with disproportionate work done by students in groups. She felt that one or two students in each

group "carried" the other students. Her other concerns related to her clarity in giving information.

Denise encountered new challenges in designing and teaching her second inquiry-based unit in the winter. The first challenge involved the reality of supporting students in choosing their own topics, designing various open-ended investigations, and carrying these out in the classroom. Although Denise had a vision of the project, all her students did not share this same vision. Her winter supervisor ascertained that "she made the assumption early that because they are 10th graders, they will want to do it. She can talk about environmental issues, and it doesn't excite them all. She's finding that her excitement doesn't translate into their excitement." During a phone conversation, Denise acknowledged that "a lot of kids are having a hard time collecting data, and they don't know what to do with it... they are dragging their feet...they need more time and more guidance."(Phone conversation 3/11/96). Denise noted "that one boy still had an experiment, although his fish had all died. But it was like pulling teeth, because he has no real intention of passing." Once her students finally decided on a topic, and set up the investigations, Denise encountered the reality of trying to manage a number of students working on different projects. "I felt like I was a person who couldn't be in 16 different places at a time." During project work times Denise's role changed every few minutes. During one period of thirty minutes Denise responded to one student's questions, gathered materials for another student,

offered advice to a third, participated in another student's survey, and tutored yet another student in using computer software.

The second challenge related to the technical writing portion of the project. Denise admitted that she entirely overestimated her students' abilities to envision a final report, and to write this to her specifications. One student described this as ""well, she started off by giving us a lot, a lot of work, just like right off, quick. She wouldn't slow down. She just kept going and going. And then once we got to our research it kind of slowed up. We knew what to expect." During one part of the unit, Denise stated that "she has taken some heat for what she is doing." At one point two parents requested a meeting with her and the vice-principal to discuss their concerns with the timelines and scope of the written reports. Denise realized that technical writing was something her students had not done.

The third challenge related to numerous interruptions to the flow of the instruction due to natural disasters, such as flooding and ice storms, and school-based events, such as the high school basketball tournament. During these times, classes did not meet for a week at a time.

Denise identified several changes in her two units that she would make if re-teaching them another year. First, she acknowledged the limiting factor of time. After several lessons, Denise commented that she needed to give students more time to work on projects in class. A second change concerned communication with parents. Denise stated that at the beginning of the project, she would send home information on the scope of the project, including all deadlines. A

third change would involve increased communication with her students. "In terms of my communication with students, I feel that I probably expected too much from them at the beginning of the unit and in retrospect, I wish I would have begun slower with the materials and homework assignments." Also, Denise would modify lecture-discussions of science content. "There were definitely times when I confused them, and a number of times when I used vocabulary (not science related) that they were unfamiliar with." (from Summative Evaluation of Teaching, 2/96) A fourth change would be to collaborate with a language arts teacher in the school, in order to strengthen her students' support in writing, making the IRP an interdisciplinary project across departments.

Discussion

Denise, like many preservice teachers, had to deal with the demands of planning new units with limited knowledge of curriculum, school context, and overall awareness of abilities and personalities of different students. Considering that inquiry-based teaching is complex and classrooms in which students engage in Standards-based inquiry are rare (Gallagher, 1989), the ability of this pre-service teacher to plan and carry out two successful inquiry-based units is remarkable. Prior to this study, it was the author's belief that creating and carrying out complex inquiry-based instructional units may realistically be beyond a preservice teacher's capabilities.

This belief was built from the author's own experience in designing and carrying out projects in secondary classrooms (Crawford, 1996) and from researching inservice teachers' attempts to change their instructional orientations (Marx, et al., 1994). One conclusion we might draw from this one case study is that preservice teachers, given certain caveats and adequate support, can feasibly create inquiry-based environments similar to those advocated in the Standards.

Denise's success in creating aspects of an inquiry-based environment raises as many questions as it provides answers. Why, in fact, did Denise stand out as an anomaly? Denise remained unique in her planning and teaching--one of twenty two students in a substantive teacher education program built on a theoretical knowledge-base promoting thoughtful student-centered opportunities to construct understandings and engage in inquiry (Shulman, 1986). Why did not more cohort teachers attempt to design and carry out similar kinds of inquiry-based units? What can we do to support preservice teachers and guide them in planning inquiry-based instruction? How successful will Denise be in her first year of teaching -- in a different context and with the added teaching load of a first year teacher --in sustaining her inquiry-based orientation to instruction?

If we accept the conclusion that novice teachers can potentially design and carry out inquiry-based instruction, the important question then becomes: what are the key steps in guiding novice teachers, who may be typical in their ability, in creating these reform-based environments? By looking at the combination of factors that influenced Denise, teacher educators may be able to

apply these findings to preservice programs as well as professional development programs for inservice teachers.

First, the data suggests that Denise's view of science as "a study of inquiry and the natural world" contributed to her engaging her students in inquiry. We know that teachers' beliefs impact their learning and teaching (Pajares, 1992), although we should be cautious in assuming that "having beliefs" necessarily translates into teaching practice (Haney, Czerniak, & Lumpe,1996.) The knowledge and beliefs of students entering teacher education programs exert powerful influences on what they learn about teaching (Borko & Putnam, 1994). Exploring preservice teachers' beliefs about teaching and about science appears an important first step in getting them to think about the meaning of inquiry-based learning environments. More research is needed in exploring how these beliefs translate into practice.

Second, Denise's clear vision of her overall goals and flow of lessons in both units enabled her to connect the teaching of process-oriented skills such as hypothesizing, designing experiments, collecting data, and drawing conclusions to the needs of her students and to the overall goals of her question-driven units. Planning extended projects requires careful attention to the sequencing of lessons. Lessons linked to solving a particular question move students toward drawing conclusions and constructing new knowledge. During the fall unit, Denise attempted to weave in ecological concepts of nutrient cycling and energy flow using the project as the framework. Research on expert and novice teachers suggests the importance of

encouraging novice teachers to plan lessons using an overview of the curriculum, rather than simply focusing on objectives of the specific lesson at hand (Westerman, 1991). This suggests the importance of preservice teachers planning long term units that relate to important questions --not simply stringing together discrete lessons related by topic. Greater emphasis on unit goals as preservice teachers plan individual lessons followed by attention to the links and cross links of individual lessons may move preservice teachers to gain an important "big picture" view of their teaching.

A third implication of this study relates to Denise's knowledge of inquiry from her 10 years of professional lab experience. If indeed Denise's experience was critical to involving her students in inquiry, how can we provide authentic kinds of experiences for all preservice teachers . We need to explore alternative ways for preservice teachers to gain knowledge of inquiry through similar kinds of experiences. One possibility is to change undergraduate science courses to include long-term investigations. Other possibilities include providing authentic inquiry experiences within science methods courses.

The fourth implication relates to opportunity. Denise had opportunity to design and carry out inquiry-based instruction. In contrast to high school teachers who design innovative units, but then fail to move them into the classroom (Lynch, 1997), Denise risked trying out a novel unit in her first field experience. With the support and encouragement from her mentor teacher and aided by her knowledge from working in inquiry-oriented classrooms, Denise worked toward

translating her beliefs in engaging students in investigations to the reality of the classroom. The importance of a supportive environment is noted in other studies (e.g. Loughran, 1997). It seems intuitive that the field placement greatly influences the kinds of instruction eventually adopted by preservice teachers. Careful selection of mentor teachers who model inquiry-based approaches appears critical Alternative ways to provide models of inquiry-based environments may include video-based case studies of what this instruction might look like. Research into constraints encountered by first year teachers that might deflect a preservice teacher such as Denise appears necessary for preservice teachers to sustain the gains made in their understanding of how to craft inquiry-based instruction.

The fifth implication points to the importance of reflection on teaching. Much has been written about teacher reflection (e.g. Munby & Russell, 1992; Schon, 1983). Denise's daily reflection focused her thinking on her students' understandings and motivated her to revise upcoming lesson plans. In this way, Denise constantly reconstructed her own understandings of learning and teaching. Denise operated in a planning, teaching, and reflective loop in which she selected teaching strategies to enhance students' understandings versus maintaining student interest (Loughran, 1994). Throughout her planning and teaching, Denise collaborated with colleagues (mentor teacher, university supervisor, fisheries expert). In some ways, Denise engaged in practical inquiry (Richardson, 1994) as she sought guidance through collaboration with her mentor and supervisor Denise remained thoughtful about how she could improve in

areas she identified, e.g. "clarity", and hoped to resolve her dilemma of needing to cover content while engaging her students in time-consuming investigations.

Conclusion and Implications

At the risk of generalizing from one preservice teacher to all and recognizing the limitations of a single case study, Denise's case study provides a positive view of what can happen in a preservice teacher's classroom. The advantage of an indepth study of one preservice teacher rests in the richness of the details of the events of the year--from planning issues to implementation issues. This case study points to giving attention to the authority of experience of the preservice teacher (Munby & Russell, 1994). Denise listened to her previous experiences as she worked towards understanding inquiry in her classroom. In order to lessen the gap between what is happening in classrooms and what needs to happen, it is teachers themselves who must make "real" the visions of the reforms. As in this study, researchers must learn from teachers' work.

Denise's case study suggests a combination of conditions necessary to enable novice teachers to create desirable kinds of inquiry-based learning environments. These conditions translate to the following implications for preservice teacher educators:

1. *Explore novice teachers' beliefs about science and about teaching science* as an important first step in getting them to think about the characteristics of inquiry-based learning environments.

2. Involve novice teachers in opportunities to *undertake authentic investigations*.

3. Scaffold novice teachers in *planning long term units that relate to important questions* and link to important content.

4. *Model inquiry-based approaches* in the field and/or through videotaped cases.

5. Engage novice teachers in *collaborative inquiry of their own teaching*.

Because this study focused on only one year of Denise's teaching, this study points to the need for longitudinal studies of preservice teachers who appear promising in their development as science teachers as they continue their journey through the treacherous first few years of full-time teaching.

The results of this study suggest that it is realistic to expect preservice teachers to design and carry out aspects of inquiry-based instruction. Expecting emergent teachers to engage in inquiry-based instruction seems especially critical in fifth-year programs that end in a terminal degree. This final year of preparation to teach presents a critical chance to promote thoughtful, innovative, Standards-based, inquiry instruction. Otherwise, we risk contributing more teachers who are complacent and comfortable with instruction based on the belief that teaching is telling. Teacher education programs need to require minimum competencies that indicate a teaching

candidate utilizes developmentally appropriate inquiry-based teaching strategies as stated in the draft Certification and Accreditation in Science Education (CASE) Standards (NSTA, 1997). It seems imperative that as teacher educators, we expect similar orientations to learning and teaching from our preservice teachers as national standards advocate for inservice teachers of K-12 grade students-- through the creation of meaningful-complex tasks that foster learning through explorations of authentic questions.

Notes

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