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Preservice Teachers' Reflections on Their Growth in an Inquiry-Oriented Science Pedagogy Course

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This study reports on student experiences in an inquiry-oriented elementary science methods course. Students in this course designed and conducted an independent investigation, and then adapted that investigation to develop an inquiry-oriented lesson and a corresponding performance assessment. Students' written reflections expressed increased understanding of inquiry-oriented science and stronger confidence in their ability to use these methods in their future classrooms.

Science educators have been challenged to develop new curricular approaches to help all students become scientifically literate. Scientific literacy has been operationally defined within major science education reform documents, such as the *National Science Education Standards* (*NSES*) (National Research Council [NRC], 1996) and *Benchmarks for Science Literacy: Project 2061* (American Association for the Advancement of Science [AAAS], 1993), as well as in various state standards documents. The *NSES* indicates that students should "develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments" (NRC, 1996, p. 105). This is a very broad and inclusive description of inquiry, one that may be difficult to implement with younger students and/or students or teachers with limited prior experience with inquiry-oriented instruction. Alternative approaches to this broad definition include using structured inquiry, guided inquiry, and the learning cycle (Colburn, 2000).

A significant thrust of these reform documents is the need to facilitate the development of scientific literacy through engaging students in scientific inquiry. Consequently, new K-12 curricula have been created with the intent of helping students develop a deeper understanding of science by doing inquiry. Although science educators view inquiry as basic to science literacy (Keys & Kennedy, 1999; Songer, Lee, & McDonald, 2003), they face numerous challenges in course design, including the tension between inquiry as a facet of nature of science instruction and the pedagogical focus of learning science through inquiry investigations (Newman, Abell, Hubbard, McDonald, Otaala, & Martini, 2004).

Many new K-12 curricula engage students in investigating questions they develop, designing experiments to test their questions, collecting and analyzing the data, and developing explanations and conclusions supported by the evidence.

Such an approach is consistent with the National Research Council's (NRC) proposed approach to using inquiry as a pedagogical approach (Newman et al., 2004). The premise is that students who conduct scientific inquiry and come to better understand it are more likely to develop a deep understanding of fundamental science concepts which can then be applied to future learning (Songer et al., 2003).

Such inquiry-oriented curricula developed for K-12 students can be effectively implemented only if there exists a cadre of science teachers competent and motivated to teach inquiry; this is not the case, however, as the classroom practice of many science teachers indicates that more attention should be given to preparing teachers for the requirements of implementing inquiry science programs in classrooms (Songer et al., 2003). Science educators in teacher education programs can address the inquiry aspect of scientific literacy by designing and delivering courses to preservice teachers that include authentic scientific inquiry experiences. This mantra has been well-established among science teacher educators, and inquiry has been a component of a growing number of science methods courses.

Unfortunately, some research indicates many science methods courses still fail to provide appropriate modeling and in-depth discussion of scientific inquiry for preservice teachers (Baxter, Jenkins, Southerland, & Wilson, 2004). Because college faculty often find themselves under constraints similar to those experienced by classroom teachers to cover a required amount of material during a semester, inquiry is too often addressed in a superficial manner in science methods courses—that is, i.e., as a topic of reading and discussion rather than as an integral component of the course (van Zee, Lay, & Roberts, 2003; Windschitl, 2003). As a result, preservice teachers are introduced to the *concept* of scientific inquiry, but may lack authentic, engaged experience with inquiry. These broad definitions and explanations about inquiry afforded to methods students provide little actual guidance for the planning, teaching, and evaluation necessary in the inquiry science classroom (Keys & Kennedy, 1999).

In addition, Songer et al. (2003) suggested that many science education faculty perceive inquiry instruction too narrowly, teaching only one model of science inquiry—that of students working independently in small groups with the teacher circulating among groups to offer assistance and guidance when needed. This style of teaching is often problematic, however, due to large class size, limited resources, and lack of experience with inquiry on the part of both teachers and students. Preservice teachers should learn multiple models of inquiry, including structured, guided, and open inquiry. In all of these models, the teacher's role is critical in posing specific questions to move students' thinking forward, diagnosing student thinking, introducing new ideas when appropriate, posing alternative or new scenarios, and so on.

A further impediment to preservice teachers' development of competence in inquiry-oriented teaching is the difficulty of establishing field placements, especially at the elementary school level, in which inquiry instruction is modeled. Preservice teachers too often are placed in student teaching environments in which the cooperating teacher focuses on reading and math to the exclusion of science, thereby denying preservice teachers the opportunity to experience the implementation of inquiry-oriented instruction (van Zee et al., 2003). Consequently, once in the field in their own classrooms, new teachers often find themselves unprepared for the challenges of facilitating inquiry lessons with their students and of managing inquiry-oriented classrooms.

Theoretical Framework

If preservice teachers develop their own research projects which are of interest to them, rather than being designated by the methods course instructor, they will more likely demonstrate increased motivation in their efforts to learn about and conduct scientific inquiry and will ultimately be more open to and more able to use inquiry in their own classrooms. Implicit here is that individuals are more likely to engage in learning about something of interest to them personally, and that familiarity with inquiry will help them be more open to using inquiry approaches later in their own instruction. This is not to assume that simply being exposed to inquiry approaches necessarily translates into one's coming to understand the nature of science, particular science concepts, or the many facets and nuances of inquiry learning and instruction.

Indeed, Crawford (2000) specifically noted that an understanding of the nature of science as well as pedagogical content knowledge and skills is a prerequisite to successful inquiry teaching. Further, simply being exposed to an inquiry approach and learning about it will not necessarily be effectively exhibited in a teacher's instruction; however, experiences in which students are guided by instructors as they learn to conduct inquiry and in which the procedures though which information is generated and validated are made explicit will help preservice teachers move towards implementing the type of science instruction envisioned by recent reform documents (Baxter et al., 2004; Newman et al., 2004; Smith & Anderson, 1999).

Likewise, science educators often assume that a good science content foundation will enable preservice teachers to conduct inquiry investigations. Adequate science content knowledge is a necessary but insufficient, foundation for inquiry learning and teaching. Although science educators may hope that preservice teachers would have had opportunities and experiences with scientific inquiry in their college science courses, in reality many of those courses fail to engage students in authentic inquiry (Smith & Anderson, 1999), focusing instead on content learning and information about science concepts. Windschitl (2003) found that only about 20% of the preservice teachers in a science methods class had previously conducted open inquiry, and even these students had only had one previous inquiry experience. An individual's acquisition of science concept knowledge does not necessarily mean that the individual understands the process through which new information is gained.

A further problem is the assumption often made by both science and science education faculty that inquiry is easy to do, that it is logical and straightforward, and that one need only know the particular procedural steps to follow (e.g., "the scientific method") to be successful doing and teaching inquiry. As a result, science educators who make such assumptions believe that their science methods students will be able to identify and investigate a scientific problem of their own devising and are surprised by their students' struggles with doing so. For example, Shapiro (1996) reported 90% of her elementary science methods students had never experienced science as an investigation, and Roth (as cited in Windschitl, 2003) reported that preservice teachers with science degrees had difficulty creating research questions, operationalizing variables that would allow for unambiguous measurements, and drawing appropriate and logical conclusions from their data. In addition to providing preservice teachers with inquiry experience, science education faculty must provide explicit instruction in inquiry-oriented science.

Further, there are multiple factors of which science educators should be aware and which should be addressed if preservice teachers are to be adequately prepared to implement scientific inquiry in their future classrooms. These factors include a complex knowledge and belief system which fits the preservice teacher's current understanding of teaching and learning and the amount of syntactic knowledge gleaned from college-level, discipline-specific science courses (Crawford, 1999; Smith & Anderson, 1999; Windschitl, 2003). All of the factors discussed above indicate a need for science methods courses that provide inquiry experience for preservice teachers as well as explicit instruction in the complexities involved with using inquiry-oriented approaches in classrooms.

Science education faculty have addressed this need for explicit instruction about inquiry in various ways (Baxter et al., 2004; Newman et al., 2004). van Zee (1998) designed an elementary science methods course which required preservice teachers to collaborate with peers and teacher researchers (i.e., master teachers who were science enthusiasts) to identify, design, and conduct an inquiry project. As a result, preservice teachers became more confident in their ability to competently teach science using inquiry methodologies (van Zee et al., 2003).

van Zee and Roberts (2001) reported on an elementary science methods course designed to help preservice teachers build on their positive science learning experiences, to articulate what they already know about successful science pedagogy, to be reflective, and to engage more successfully in inquiry learning. The use of reflective journaling, drawings, and the modeling of inquiry practices helped better prepare preservice teachers for engaging in pedagogical inquiry. Students in the class commented favorably that this class was taught using the inquiry method (modeling of inquiry), whereas other courses they had taken were limited to lecturing about how to do inquiry.

Students in another science methods course were introduced to inquiry, and after it was discussed, students were required to generate and investigate their own science-related questions (Windschitl, 2003). At the conclusion of the course, many students were more enthusiastic about using inquiry; however, this enthusiasm did not result in a consistent implementation of inquiry teaching practices, with only half of the students using inquiry in their subsequent student teaching. Thus, it would seem that having experience with inquiry projects alone is not enough to ensure that preservice teachers will use inquiry teaching methods in their future classrooms.

Crawford (1999) described a case study of a preservice teacher (MAT) who was learning how to design and implement inquiry learning in her classroom. Crawford pointed out that preservice teachers can—with adequate support—create inquiry environments in their classrooms. She noted that the support enabling the preservice teacher to accomplish this included a strong mentor teacher who utilized scientific inquiry, some prior experience in project-oriented classrooms, access to outside content experts, and consistent and thoughtful reflection on teaching practice. Crawford made five recommendations based on this study: (1) preservice teachers' beliefs about science and teaching need to be explored if they are to begin thinking about inquiry-based learning environments (i.e., teacher beliefs influence their learning and teaching); (2) preservice teachers must be provided opportunities to undertake authentic inquiry investigations of their own; (3) models of teaching scientific inquiry in field placements must be provided; (4) preservice teachers need to be guided in relating science content and concepts to the research questions they pursue; and (5) preservice teachers must have opportunities to collaborate with peers, mentor teachers, and external experts (see also Hogan & Berkowitz, 2000; Keys & Kennedy, 1999).

Cantrell, Young, and Moore (2003) followed the development of science teaching self-efficacy in a cohort of preservice teachers through their initial methods course, an advanced methods course, and their student teaching experience. Among these students, confidence in their ability to teach science varied by gender, science experiences in high school, and amount of classroom science teaching experience. Among the recommendations resulting from the study was the suggestion that preservice teachers need experience actually developing science lesson plans and implementing them in the classroom. Baxter et al. (2004) made designing inquiry lessons an integral part of their science methods courses in which preservice teachers engaged in content immersion during field trips, developed researchable questions based upon their field trip experiences, and designed experiments to inquire about their questions. Upon completion of their experiments, the preservice teachers were required to create teaching units (lessons) from those experiments and then to teach those lessons to children in public schools, with the goal of having the preservice teachers engage in "direct transfer of learning by inquiry to teaching by inquiry" (p. 214). Based on student reflections over several semesters, Baxter et al. adapted their methods courses to include numerous examples of transferring inquiry activities into inquiry teaching.

Purpose of the Study

The present study is based on an undergraduate science methods course in which preservice teachers conducted an independent inquiry investigation and then developed an inquiry lesson plan for elementary students, including a performance assessment. The purpose of the study was to investigate the degree to which (1) designing and completing inquiry investigations influenced the ability of the preservice teachers to design science lessons using inquiry approaches, and (2) completing the inquiry investigations and their corresponding inquiry lessons influenced their confidence and motivation to use inquiry-oriented pedagogy in their future classrooms.

Description of the Inquiry-Oriented Science Methods Course

The elementary science methods course described in this study is designed for a typical 16-week semester. The course approaches inquiry along two strands. The first strand is having students contribute to the knowledge base of the course by researching science education literature (including websites) to obtain information relating to topics specified by the instructor. Students are placed in cooperative groups, and each member of the group takes on the responsibility of researching a given topic and reporting the findings to the group. Once each group has completed this sharing of information, the topic is discussed by the whole class. Discussion is then followed by one or more activities which illustrate or model appropriate pedagogy related to the topic. Research topics include not only scientific inquiry, but also the foundational elements necessary for conducting successful inquiry. Examples include science process skills, children's thinking relative to inquiry, scientific literacy, constructivism, assessment (particularly performance-based), and application of learning theories to the inquiry process and pedagogy.

The second strand consists of major course projects completed by the students. There are four major projects: (1) an individual inquiry project, (2) the development of a lesson plan based on the inquiry project, (3) the development of a performance assessment based on the lesson plan, and (4) a cumulative course portfolio.

Individual Inquiry Project

Each student is required to select a science topic of personal interest, compose a related research question or hypothesis, research background information about the scientific principles and concept(s) involved, design and conduct an experimental study to test the research question or hypothesis, and report the results and conclusions. This project is done independently and requires each student to utilize what he or she knows and has learned during the early part of the course regarding inquiry (e.g., hypothesizing, identifying and controlling variables, measuring, etc.).

Instruction focuses on the particular skills (such as science process skills) necessary for successfully conducting inquiry investigations. Black box activities, Cartesian divers, pendulum activities, etc., are used throughout the course as models of different levels and different aspects of inquiry. Inquiry's flexible use of science process skills in designing investigations and responding to changing needs is compared to the often more rigid use of the "scientific method" in which procedural steps are laid out in advance.

Attention is also given to similarities and differences between open inquiry and guided inquiry. Although the inquiry project selected by the preservice teacher is an open inquiry investigation, it is pointed out that elementary children need scaffolding to enable them to conduct open inquiry, particularly when first learning to do investigations, and that a guided inquiry approach is often more appropriate in such contexts.

Lesson Plan

After completing the individual inquiry project and receiving feedback from the instructor, each student creates a lesson plan based upon his or her inquiry project. The lesson plan must be targeted to a specific grade level and be designed to engage elementary students in conducting the same experiment (in whole or in part, depending upon what would be most appropriate for the targeted grade level) or a related inquiry-oriented investigation. A lesson plan format based on the Activities Integrating Mathematics and Science (AIMS) series is provided for students to use in presenting their lesson plans.

Although the AIMS format is often cited as a traditional lesson plan model rather than an inquiry-based model, the format is useful to beginning teachers in that it provides specific elements which are important in developing lesson plans and can thus serve to guide students through the process. As examples, the AIMS' elements of "key question" and "background information" can help students maintain focus on the question they are investigating and the science concepts related to that question. The "discussion questions" help students consider how to probe children's thinking and how to help children move beyond current levels of understanding to introduce new ideas and begin making connections to the world beyond the classroom. In keeping with the idea that a guided inquiry approach is sometimes more appropriate for elementary children than open inquiry, some procedural steps in the AIMS lesson plan format can be relatively specific; however, procedural steps can also be stated in terms that are more open-ended. For example, a step may ask that the experiment procedures developed by the students be written out and submitted to the teacher, or that some rationale or justification for a hypothesis be provided. Lesson plans may also begin with a more structured whole group activity and then ask students to identify specific factors to investigate further and to design the procedures to do so. In this way, the instructional approach utilized for the class project differs from that used in many of the original published AIMS materials while maintaining the usefulness of the AIMS format.

Assessments with Rubric

Students are next required to develop a performance assessment based upon the inquiry lesson plans they developed. The assessment must address specific objectives and focus on the concept(s) elementary students are expected to learn by completing the lesson. Students must also create a rubric for the assessment.

Cumulative Course Portfolio

Throughout the semester, students are asked to reflect on and analyze their experiences in the course during small group and whole group discussions. These reflections include students' perceptions of their growth in learning about science and about the teaching of inquiry-oriented science, and what they learned by doing each of the above-described projects. Towards the end of the course they are asked to develop written reflections on how different aspects of the course contributed to their development as teachers of science. These reflections are included in a course portfolio submitted at the end of the semester.

Methodology

Participants

Participants were 34 students at a midsize, private, comprehensive university in a Midwestern community of approximately 120,000 people. They were enrolled in the required junior-level elementary science methods course described above. All had previously taken one general methods course, and the majority had taken or were concurrently taking other subject-specific methods courses. Many were involved in a field experience of two hours each day. The majority of the students in the class had completed the university requirement of 11 semester hours of science courses.

Data Analysis

The data sources in this investigation were the students' reflective essays that were submitted at the end of the course as part of the course portfolio. This portfolio included all of the students' work for the semester, with each assignment accompanied by a brief reflection and a longer summary reflection at the end. Reflections were analyzed using guidelines provided by Boyatzis (1998). A list of categories was developed from the theoretical framework of the study. Additional categories emerged during an initial reading of one third of the students' reflections. This final list of categories was then used to analyze all of the reflections and is provided in Table 1. Reliability was addressed by double coding of selected essays, recoding to check for coder drift, and having a second rater evaluate one third of the essays. Because we were coding for the simple presence or absence of the codes and the codes were nominal data, a percentage agreement score was calculated. Initial percentage agreement scores ranged from 86% to 100%. Coding discrepancies between the two raters were discussed to check for sources of the variation. Some discrepancies were the result of different interpretations of minor points and were resolved; other were true discrepancies and were retained as such. The final percentage agreement score was 97% across all categories.

Table 1. Student Reflections

	#	%
General positive comments on experience	32	94
General negative comments on the experience	2	6
Comments related to science content knowledge		
Connected learning to personal life experiences	10	29
Comments related to science methods or science pedagogy		
Never done before/not done in a long time	9	26
Struggle to identify a problem, operationalize variables, etc.	20	59
Increased learning of inquiry science/process skills	26	76
Increased confidence in ability to teach inquiry science	29	85
Increased enthusiasm/willingness to teach inquiry-oriented science	9	26
Improved attitude towards science	20	59
Benefits to future students		
Identified difficulties future students will encounter	8	24
Student choice/control/ownership	9	26
Awareness of science in world/ability to examine claims	7	21
Will remember longer by doing it than by instructors talking about it	3	9
Comments on creating lesson plans		
First time creating a totally original lesson plan	5	15
Helpful to get experience creating an original lesson plan	6	18
Increased confidence to create science lessons	12	35
Better able to evaluate other lessons after creating own	3	9
AIMS was a good model; will use	12	35

Results and Discussion

The majority of the students (94%) were very positive about the projects in which they participated during this course as well as about their growth as future teachers of elementary science (see Table 1). Two students expressed negative evaluations of the experience. Their evaluations were based on the time-consuming nature of the projects and the difficulty they had in completing them. The largely positive nature of the responses may have been influenced by the fact that the reflections were part of a course portfolio to be submitted to the instructor; however, several factors mitigate this concern: students were told that professional critique of the course and assignments was appropriate and had opportunities to practice this form of feedback during the course, comments on the anonymous course evaluation completed at the end of the course were similar to those found in the portfolio reflections, and the specific comments made by the students in the reflections demonstrate progress in the areas of interest.

Independent Inquiry Projects

The most important goal of this series of projects is to provide direct experience for these future teachers in conducting inquiry projects with the goal that they will use the skills developed to guide their future students in inquiry projects. As found in previous research (Shapiro, 1996; Windschitl, 2003), very few students had previously engaged in inquiry investigations. Over one fourth of the participants in this study stated that they had never (or not in a very long time) designed and completed an investigative project on a question that interested them. Perhaps related to this lack of experience, well over half (59%) described their struggles or learning experiences with selecting a question; writing a testable hypothesis; identifying the independent, dependent, and control variables; and completing the investigation. This is illustrated by the following student excerpt:

> *In all of my science classes, every experiment we have ever done has been completely laid out for us step by step. Because of this, I never really thought about all the components an experiment has. In the past, I have learned about the components, like variables and controls, but never really had to set them for myself. This was somewhat of a challenge for me to figure out all the controls and how to make sure they do not change. There were so many different things that I had to keep the same that I would never have thought of if the experiment was created by someone else.*

Learning to think in these unaccustomed ways about the questions they were investigating was difficult for most of the students; however, in spite of this, these students (85%) felt that the experience was worthwhile because it increased their confidence in their ability to teach inquiry science. One fourth of the students specifically mentioned their increased enthusiasm to teach inquiry-oriented science lessons in their future classrooms as a result of their experiences in this course.

> *This activity helped me develop something that I know I will use in my science classroom. I am student teaching in a sixth-grade classroom next semester, and I truly hope that I will be able to use this format with my students. I would like to perform this exact experiment and see what the real-life results will be [with elementary students]. Then, I would like to let each group decide on a different topic they find interesting to perform an additional experiment study. I can't wait!*

This student's interest in having her students replicate her original experiment is a concern. While the experiment was inquiry-oriented for her in that she initiated the question and developed the procedures, having her students perform the "exact experiment" would not be inquiry for them; however, she does indicate that she would then have them select a topic to investigate on their own. A very successful approach to inquiry is to begin with a more structured format and then have the students proceed independently (Colburn, 2000).

Preservice teachers also demonstrated an increased understanding of the nature of science and the role of inquiry instruction in helping their future students develop a deeper understanding of the nature of science. The importance of hands-on inquiry investigations in developing this understanding in their future students is described by the following preservice teacher:

> *In the past, scientific knowledge was generally perceived as a collection of statements about the world. I have realized that scientific knowledge provides conceptual and technological tools that allow people to describe and explain how the world works and to achieve a richer understanding and appreciation of the world they experience. It is important to help children engage in experiences that require them to use scientific knowledge and processes as tools as they make sense of their experiences. This demands that the science classroom be transformed into an inquiry-based culture where curiosity, creativity, and questioning are valued; where resources and opportunities are made readily available; and where students can "work" like scientists. Children will come away from these experiences with the ability to use scientific knowledge to describe, explain, predict, and control their world.*

Many students (58%) reported an improved attitude towards science in general, describing earlier experiences with science that had turned them off or simply failed to excite their interest and curiosity. They also discussed their improved ability to evaluate claims/products as consumers (29%) and to find the answers to science-related questions that occurred in their lives:

My enthusiasm and interest in science has been GREATLY ENHANCED by my participation in this course!

While thinking about what I wanted to do as an experiment, I became aware of how many claims are made by companies regarding their products. I realized how adults as well as children are bombarded with information which could be tested scientifically to see if it is correct. This showed me how important it is for children to understand how to reasonably process information they encounter from many sources.

I learned that that should be the main goal of science education—to be able to apply science to everyday life and be able to use the knowledge of science to make informed decisions. To accomplish this task, teaching should focus on the scientific process skills rather that simply on the content knowledge, though that is also important. By using the constructivist approach to teaching, these things can be accomplished.

The approach to science instruction based on process skills described by this student was another major focus of the course. Many students came to the science methods course with a view of science as being limited to a rigid vision of "the scientific method." They had learned it during cookbook labs and were not really aware of how to design an investigation to answer a question that concerned them. One student describes this transition as follows:

In the beginning I was hesitant. The ideas of independent variables and dependent variables somewhat confused me. The entire scientific method, which had been drilled into my head from the fifth grade, still had no practical application for me. Once I started on the project, though, I was hooked. The independent and dependent variables made sense when I actually had an experiment before me. The scientific method, which had always felt so restricting, provided me with a basic framework for the experiment but did not dictate what I had to do next.

As seen above, the students initially were unsure of their ability to complete the assigned investigations; however, as students gained more experience with their own inquiry projects, they began to see how the process skills could be used in instruction with their own future students. Three fourths of the students discussed their increased awareness of process skills as well as their ability to use them in science instruction.

As [future elementary] students engage in each of these [science] processes, they will develop the ability to think critically and use inquiry to acquire ideas and information on their own.

I learned about the science processes and how they all interact with each other, like a cycle of events, where one leads to another. I also have noticed a huge difference in how I look at the science process skills. At the beginning you could have asked me to list them and you might have received half of them. Now I could mention all of them and can explain how they are used in many different situations, including our everyday lives.

I really started to notice the process skills appearing in every class activity. Just think what you can do with them for a whole year in your classroom!

The focus in this initial part of the course is to introduce inquiry methods and to enable the students to successfully conduct an inquiry investigation of their own design. During the course of the semester, many students overcame an initial reluctance to approach science investigations, with the majority of the students increasing their understanding of the nature of science and the role of scientific inquiry in elementary science instruction. Having successfully grappled with new ways of thinking in the first part of the class, the students moved on to create lessons based on their experiment studies.

Lesson Plans Created from the Inquiry Projects

Over one third of the students (35%) reported that the inquiry-oriented science lesson they created from the experiment activity would be a model that they would use in the future, as expressed by this student:

Prior to this assignment, I asked myself, "How do I begin to develop some expertise in these strategies called inquiry?" I want to empower students to ask their own questions, devise methods to explore those questions, and develop their own answers to their questions. Having experienced this type of learning, I gained a greater level of confidence to better incorporate this type of inquiry-based, hands-on science teaching. I also feel more confident and have a greater understanding about inquiry learning and its role in science learning.

They also expressed increased confidence in their ability to create science lessons based on their experience of having created a lesson from their own inquiry investigation, thus supporting the suggestion by Cantrell et al. (2003) that students would benefit from the opportunity to develop science lesson plans of the type that they will be expected to use in their teaching experiences.

This has been the most meaningful lesson plan I have written because I have never experienced writing a lesson from something that was completely originated by me.

It was nice to gain experience in writing experiments so that if by some chance I cannot find one dealing with the desired topic, I can write my own. The lesson plan reinforced many of the ideas learned in the experiment study and taught me what was important when I am designing and implementing experiments for my own classroom some day. It will also be helpful when evaluating previously written experiments and will help me to decide what is and is not appropriate for my students:

A common concern in writing the lesson plan was the importance of balancing the need to provide sufficient guidance for students, especially those with little previous inquiry experiences, with their desire to incorporate more choices for the students as is consistent with inquiry instruction.

Completing the lesson plan was the greatest learning experience for me. By completing this activity, I learned the importance of creating a lesson plan that will allow the students to find meaning without forcing them to follow specific directions or procedures. It is very important to allow students to find meaning by providing them with instructional materials and guidance, without forcing the outcome of their actions and results. I also *learned the importance of allowing students to design their own experiment in order for them to get more from it. As a teacher, it can be very hard to let go of the control and allow students to make their own choices.*

Initially, I was very unsure about how to make this lesson inquiry-based. I just could not figure out what part to let students do on their own. I finally decided to let the students create their own procedures because I felt like that was the part of the experiment study that I learned the most from. I felt like writing the procedures made me consider and use many of the process skills, and I wanted to re-create this for my students. It was challenging to create student pages that guided the students without giving them too much information.

This concern for the difficulties that their future elementary students might experience when engaged in inquiry activities was expressed by nearly one fourth of the participants (24%). They also identified benefits to their students, including students having more choices and thus more ownership due to increased input (26%), an awareness of science in their world and the ability to use science process skills to evaluate situations they encounter (21%), and the fact that learning is enhanced when students are actively engaged rather than passive:

It is important to know what is expected of your students, and there is no better way to learn that than to go through it yourself. For this activity, I really wanted the students to have control over what was done. I really enjoyed being able to decide on my own experiment design and figured they might do the same. It made it more of a challenge to design it that way, rather than taking control and telling them exactly what to do, but I feel that the benefit that they will gain is worth it.

I am happy that we were allowed to choose our own topics [for the experiment study] because that always ensures that the experiment will mean more to the student. I would like to use an experiment assignment similar to this one in my future class. I think that kids would really enjoy getting to test certain things of interest to them and it would be a good assignment for some parent involvement.

After creating an experiment study, thinking about it in terms of teaching it to students put it in a new perspective. I had to think about how students would need to approach each step and how much support I would give them.

As can be seen from the excerpts above, students in the course began to see applications from these assignments that went beyond the design of a science lesson plan. In addition, a number of the participants who were concurrently involved in a field experience reported informally that the skills required to adapt their experiment study to a lesson plan were helpful in other subject areas and situations in their current field assignments.

Designing a Performance Assessment

As assessment is an integral part of instruction, the students were required to develop a performance assessment (including a detailed rubric corresponding to the assessment activity) to be used with the inquiry lesson created from their investigations. The students found the assessment project difficult; again, as in the experiment study, they had to approach a lesson in a new way. Although they had used rubrics in previous methods courses, for many of them this was the first time they had to create a rubric on their own. They discussed the difficulty of having to determine expectations and levels of competence in a more detailed way than they had previously done. They were surprised at the difficulty of this task, but they felt that it would benefit their future students:

> *I had no idea before completing this assignment how difficult creating assessment tools would be. I found it extremely difficult to construct solid grading criteria based on the lesson that I had created. I believe that it taught me to think ahead more about what I actually want my students to learn, rather than what I think will be interesting to teach. . . . Now, I know that for me it is best to pick a topic and then determine what I expect students to gain from a lesson. I can then create the lesson to correspond to state standards and goals.*

> *In order to complete this assignment, I carefully examined what my expectations were for students in the AIMS lesson. I then tied these expectations to the experiment study/presentation rubric I created. The assessment project tied the experiment study and AIMS lesson plan together and I will use it in the classroom.*

Their responses indicated an increasing awareness of the interdependence of instruction and assessment. Students also gained experience in creating the performance assessments necessary to appropriately evaluate inquiry-oriented science instruction.

Conclusions

The *NSES* (NRC, 1996) and AAAS (1993) standards, among others, promote the development of scientific literacy in students and focus on scientific inquiry as an important avenue through which this can be accomplished. As science teacher educators, we continue to search for the optimal set of experiences which will both inspire and enable future classroom teachers to be effective teachers of inquiry-oriented science. A major premise of the methods course described here is that preservice teachers are more likely to utilize inquiry approaches in their future teaching if they have a deep understanding of what inquiry is and how it can be used pedagogically. The reflections of these preservice teachers provide some evidence that authentic first-hand inquiry experiences must be included in this set of experiences as well as practice in translating these experiences into inquiry-oriented lessons appropriate for their future students.

As with most studies, however, several cautions are in order in applying this evidence. The first is a consideration of the degree to which the exposure provided these science methods students is sufficient to prepare them to engage in inquiry instructional approaches. As Newman et al. (2004) noted, a single semester course by itself may be insufficient to provide all the instruction and experiences required by students for them to become effective inquiry teachers. They identified seven dilemmas of teaching inquiry in a science methods course, any one of which could potentially result in preservice teachers not using inquiry in their later instruction. These factors included varying definitions of inquiry, lack of sufficient inquiry-based science-learning experiences, perceived time constraints to conduct inquiry, a need to strike the appropriate balance between science instruction and pedagogy instruction, instructors' and students' lack of inquiry-based learning experiences, grade versus trust issues, and "sciencephobia." It is our hope that the experiences in this methods course will alleviate some of these pressures.

The *NSES* (NRC, 1996) stresses as that students be engaged with scientifically oriented questions, that priority be given to evidence, that students formulate explanations from that evidence and evaluate those explanations in light of alternative explanations, and that they communicate and justify those explanations. The elementary science methods course described here has incorporated those same tenets, beginning with the individual inquiry project. Specific levels of inquiry were modeled for students in the course, a practice also reported by others investigating inquiry learning in science methods courses (Baxter et al., 2004; Newman et al., 2004). Similarly, direct instruction of necessary knowledge about inquiry (both science as inquiry and science through inquiry) was included in the course through topic reports, discussion, and selected activities and science learning experiences. Both Baxter et al. (2004) and Newman et al. (2004) suggest that explicit discussion of inquiry-based instruction is important, and simply exposing students to inquiry through sample activities or discussion about it is insufficient. In-depth examination of what students are learning and how they are learning it is critical, and misconceptions students hold or form may be masked during their engagement in open inquiry or purely constructivist environments, which may otherwise be exposed through direct or explicit instruction as well as more structured forms of inquiry. Follow-up and support during student teaching will strengthen these experiences and provide more information about the influence of such experiences in methods courses on later instructional decisions.

Another caution is that although these preservice teachers have expressed their intentions to use inquiry-oriented lessons in their future classrooms, these decisions remain to be made as they move into their student teaching assignments and their eventual job placements. Observation and evaluation of their instructional practices during student teaching need to occur to confirm whether this truly occurs. Similarly, data need to be collected about these students' science teaching once they are in their own classrooms. Following these preservice teachers into their later classrooms will provide more conclusive evidence of the degree to which these experiences enabled students to gain enough understanding to use inquiry effectively in their own teaching.

Implications

The implications for science educators are clear. Instructional approaches which merely advocate inquiry-oriented teaching without also providing direct experience are both insufficient and contrary to inquiry learning. Both experience and research have revealed that students tend to teach as they were taught. These future teachers will enter their own classrooms having engaged in authentic scientific inquiry, translated that experience into knowledge of how to use inquiry as a pedagogical approach, and developed a deeper understanding of their role in supporting students as they develop their own skills in inquiry. They are thus one step closer to being able to implement inquiry instruction in their own classrooms.

Just as we would expect our preservice teachers to engage their own students through dialogue and questioning to determine their grasp of concepts and ideas, so too must science teacher educators carefully examine what students in their science methods courses are learning. As we continue to work toward full implementation of the goals outlined in reform documents (AAAS, 1993; NRC, 1996) and the benefits to young people of having the ability to use a deep understanding of science in their lives, we must continue to explore the factors conducive to the development of science teachers who will make these changes possible.

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