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Conducting Science Inquiry in Primary Classrooms: Case Studies of Two Preservice Teachers' Inquiry-Based Practices

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Abstract

This study examined the impact of an intervention designed to promote inquiry-based instruction among early childhood/elementary preservice teachers in Earth science. Preservice teachers participated in training sessions and community-based internships to deepen Earth science content knowledge and develop inquiry-based practices. Analyses of Earth science content knowledge pre- and posttests reveal mixed results: four of the eight participants' posttest scores increased over the duration of the study, two participants' posttest scores remained the same, and two participants' posttest scores decreased. Results of the Science Teacher Inquiry Rubric (STIR) (Bodzin & Beerer, 2003) also show mixed results with four participants who exhibited student-centered practices and four participants who engaged in teacher-centered practices. Two preservice teachers with different profiles were selected for in-depth case studies. Findings reveal the importance of preservice teachers' conceptions of science inquiry and the school environment. We concluded that appropriate conceptions and supportive environments are prerequisite to sustaining prospective teachers' inquiry-based practices.

Introduction

Inquiry is critical to learning science (Eick & Reed, 2002; Haefner, 2004; Windschitl, 2003). The *National Science Education Standards* (*NSES*) (National Resource Center [NRC], 1996) describe *inquiry* as "authentic questions generated from students' experiences" (p. 21). The *NSES* further assert that

> When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students' activity develops their understanding of science by combining science knowledge with reasoning and thinking skills. (p. 2)

While preservice teachers' ability to implement inquiry-based instruction has been studied extensively in the literature (Bianchini & Colburn, 2000; Eick & Reed, 2002; Haefner, 2004; Kelly, 2000; Windschitl, 2003), few studies examine inquiry-based science teaching in primary classrooms because such practices are particularly rare in these settings (Harnik & Ross, 2004; Riggs & Kimbrough, 2002). Far too often, direct instruction is the order of the day in K-6 classrooms. The purpose of this article is to examine the inquiry-based practices of two early childhood preservice teachers and to inform the science education community about the complexities of teaching young learners through inquiry.

We add to the body of knowledge on inquiry-based instruction in science by examining the practices of preservice teachers who participated in the Earth Links study. The goals of the Earth Links study were to enable a diverse group of early childhood/elementary preservice teachers to work with an established science curriculum (i.e., *Investigating Earth Systems* [*IES*], 2001) and implement it in formal and informal education settings in order to enhance their inquiry-based practices. *IES* uses the Earth Systems Science framework. This framework was initiated in 1991 to support the development of interdisciplinary courses among college faculty with a focus on global change (Johnson, 2006). Realizing that many primary and elementary teachers have limited experiences with inquiry-based teaching, Earth Links provided supports such as mentoring by graduate students and faculty, community-based internships, training sessions, and curriculum and materials support during student teaching.

The three research questions that guided this study were the following: (1) How did the study participants' geoscience content knowledge change over time?, (2) How did the participants in the study enact inquiry-based practices during student teaching?, and (3) How did target participants' understanding of science inquiry and geoscience content knowledge influence their inquiry-based practices in primary classrooms? Our intent was to collect and use process data to help us understand the nuances and complexities of inquiry-based instruction in early childhood settings and to inform future research.

Theoretical Framework

Drawn from the tenets of constructivist learning theory (Eick & Reed, 2002), inquiry has been characterized as both an orientation (i.e., nature of science) and a process (i.e., method of science) (Bianchini & Colburn, 2000). Lambert (2007) describes the processes "as knowing, inferring, analyzing, judging, hypothesizing, generalizing, predicting, and decision-making" (p. 389). The scientific method allows students to identify the problem, formulate a hypothesis, design an investigation, make and record observations, interpret data, and explain the results (Crawford, 2007; NRC, 1996). Bodzin and Beerer (2003) used the processes of science to develop the Science Teacher Inquiry Rubric (STIR). The STIR can be used to rate inquiry-based practices across six categories (those categories are explained later). We used these categories to obtain process data on the inquiry-based practices of prospective teachers in their first year of the study.

In practice, Windschitl (2003) describes four types of science inquiry: (1) *confirmation* experiences or "cookbook labs" that are used to verify a known fact, (2) *structured inquiry* through which students are given the question and procedure to discover an unknown answer, (3) *guided inquiry* through which teachers allow students to investigate a prescribed problem using their own methods, and (4) *open inquiry* through which students form their own questions and conduct independent investigations (p. 114). We used these descriptors to categorize science lessons taught by preservice teachers to learn what types of lessons they offered students in different learning contexts.

Review of the Literature

Four bodies of literature informed the development of our research study: (1) inquiry-based teaching and learning among preservice and practicing teachers, (2) development of pedagogical content knowledge, (3) field-based experiences, and (4) learning environment. Studies in each of these categories that inform our research study are presented next.

Inquiry-Based Teaching and Learning

Windschitl (2003) conducted a multicase study of six secondary science preservice teachers' inquiry-based practices. One female and five male prospective teachers were observed during a classroom inquiry project and also during a nine-week practicum. Windschitl conducted a cross-analysis of the cases by comparing prospective teachers' previous inquiry-based experiences, classroom observations, and journal writings. Findings revealed that all participants had difficulty formulating questions or hypotheses to investigate. Furthermore, the inquiry project in which they participated during their science methods course had little impact on their classroom practices. Windschitl found that open inquiry is difficult for preservice teachers to implement and, as an instructional practice, it is tough to sustain. Only three of the participants engaged in regular use of guided or open inquiry. The only common experience among these three participants was their prior long-term, research-based experiences wherein they engaged in authentic scientific investigations. Since previous experiences are powerful influences on preservice teachers' classroom behaviors (Eick & Reed, 2002; Morrell & Carroll, 2003; Windschitl, 2003), we believed that providing novice teachers with training on the use of a guided-inquiry curriculum and a community-based internship would enhance their inquiry-based teaching in early childhood and elementary classrooms.

Development of Pedagogical Content Knowledge

Shulman (1987) describes pedagogical content knowledge (PCK) as one of seven domains of teachers' professional knowledge. He purports, "teaching . . . begins with a teacher's understanding of what is to be learned and how it is taught" (p. 7). Thus, PCK can be modeled in science methods classes. For example, teacher educators often use modeling and multimedia to show prospective teachers best practices (Yoon, Pedrettie, Bencze, Hewitt, Perris, & Oostveen, 2006). Preservice teachers can also develop PCK by reflecting upon their own practices with students in formal and informal school settings (Wilson, 1996). Professional development also plays a role in the development of PCK.

Mellado (1998) studied the development of PCK among preservice teachers by examining their conceptions about science teaching. Participants' conceptions of themselves included such metaphors as father, sage, leader, elder brother, guide, and orientor. Case studies of four preservice teachers revealed that they began their instruction by eliciting student ideas to engage them in science activities. Only one preservice teacher's behavior was consistent with her preconceptions of teaching and learning science, however. Mellado concluded that it is necessary to encourage reflection as a first step in generating better-suited conceptions and practices among preservice teachers. This finding is important because it pinpoints the need to examine teacher conceptions of science inquiry and how it influences their behavior in the science classroom.

Dickerson, Dawkins, and Annetta (2007) conducted a three-year study that investigated the impact of professional development on the PCK of Earth and environmental science teachers. The “Earth View: Leadership in Earth/Environment Science for North Carolina Schools” program engaged inservice teachers in inquiry-based scientific experiences through which they were encouraged to pose and answer their own questions about the environment in order to grow professionally and become leaders in their schools. Data sources included concept maps and structured interviews. Analysis of the concept maps showed that all participants’ pre- to post-concept mapping scores increased. The paired difference revealed a mean of 19.83 implied and explicit appropriate connections. Thus, the researchers concluded that they were able to influence content knowledge about Earth and environmental science. Coupled with qualitative data gathered from structured interviews, the implications were that scientific fieldwork has the potential to enhance PCK among secondary Earth and environmental science teachers. These findings support the position that providing preservice teachers with appropriate teacher training and field experiences through which they use inquiry increases the likelihood that these teachers will engage their own students in science inquiry (Kean & Enochs, 2001; Lambert, 2007).

Field-Based Experiences

The Washington Earth Science Initiative (WESI) provided a context for learning about the importance of field-based learning (Field, DeBari, & Gallagher, 2003). An intensive, three-week K-12 science teacher institute set out to assist local teachers by providing them with the professional development and support needed to create and initiate community-based projects that addressed real environmental issues in the state of Washington. During professional development, teachers strengthened their background knowledge and skills, learned how to use technology as an instructional tool, and established community-based connections. However, after gathering results from four years of institutes, researchers of WESI reported mixed results. Teachers expressed a great deal of satisfaction with the program but had difficulty implementing planned projects in school. In addition, though efforts were taken to focus on more inquiry-based activities for children, teachers still tended to “rely heavily on lecture- and textbook-oriented instruction” (p. 60). Thus, getting teachers to enact and sustain inquiry-based practices pose certain challenges. In the Earth Links study, we wanted to learn about these challenges in order to reduce barriers that inhibited the instruction of science inquiry.

Learning Environment

Lave and Wenger (1991) suggest that all learning is situated in a context. In other words, the teaching/learning environment influences prospective teachers’ practices. While educational histories—that is, prospective teachers’ own K-16 experiences—have a strong influence on their practices, mentors and cooperating teachers exert strong influence on their practices as well (Bianchini & Cavazos, 2007; Bianchini & Colburn, 2000; Windschitl, 2003). In Crawford’s (2007) study, some prospective teachers learned that teaching science inquiry was not the order of the day in their high school. Statements such as “It does not work with my kids,” “They are concerned about their grades,” “They are lazy,” and “They just want to get through" (p. 635) caused some prospective teachers to change their beliefs and abandon inquiry-based practices learned in teacher education programs.

Constraints may also arise because of the cultural context of the school itself (Bianchini & Cavazos, 2007; Crawford, 2007). Bianchini and Cavazos (2007) found that school culture impeded two beginning teachers' inquiry-based practices. Negative feedback from peers who had challenging experiences and negative advice from mentors who did not practice inquiry to the same degree influenced these two participants to change their views. In one case, student inquiry was reduced to classroom demonstrations instead of individual or small group work. In order to teach science inquiry in formal school settings, preservice teachers must have appropriate environments in which to practice. Thus, the school environment may enhance or inhibit prospective teachers' practices. If the school climate is supportive of science teaching in general and inquiry-based practices in particular, then preservice teachers have the opportunity to develop best practices.

Methods

We used the case study method to examine preservice teachers' inquiry-based instruction in Earth science over a two-year period (from 2003 to 2005). We chose to work with a small number of preservice teachers to develop rapport and to influence their teaching and learning of Earth science and their pedagogical content knowledge as it is related to inquiry-based science teaching. The case study method is appropriate for this type of work, allowing us to gather both quantitative and qualitative data in multiple settings and to report on the development of individual preservice teachers (Krathwohl, 1998). The results presented in this article, however, focus on the Year 1 cohort.

Setting

The college of education where the study took place is situated in an urban city in the northeastern United States and enrolls approximately 2,100 undergraduate and graduate students each year. After admission to the teacher education program, third-year early childhood/elementary preservice teachers have two different kinds of field experiences: (1) in reading/language arts and (2) in mathematics/science. During the practicum, preservice teachers are grouped into teams of four persons and spend two, three-hour days in the schools working with cooperating teachers. Sometime during their fourth year, preservice teachers enroll in student teaching, which is a 15-week field experience in the schools.

Recruitment

After receiving more than 30 applications for the study, 12 preservice teachers (one White male, four African-American females, and seven White females) were selected to participate in the study. All of the preservice teachers were early childhood/elementary education majors. All but two of the preservice teachers were traditional college-age students; the other two were 26 and 40 years old. The mean grade point average (GPA) of this cohort was 3.45, and the average number of credits in science content courses was ten. Specific course-taking patterns for this cohort were as follows: nine courses in biology, two in chemistry, four in physics, three in Earth science, and ten in environmental science. The course-taking pattern indicated that this cohort was less knowledgeable of chemistry, Earth science, and physics and could benefit from the study. Eleven participants took part in the study from Year 0 to Year 1. One participant dropped out of the study in Year 0 for personal reasons.

Data Collection and Procedures

At the outset, we met with project evaluators and advisory board members to discuss the design and implementation of the Earth Links study. We developed and administered an Earth science content test on a pre/post basis to measure content knowledge of Earth science before and after the study. The items on the content test were developed from released Earth science items on the National Assessment for Educational Progress (NAEP) (Institute of Education Sciences [IES]/National Center for Education Statistics [NCES], 2008). Weighted alpha reliability levels were within an acceptable range, reported to be between 0.68 and 0.82 for NAEP science item blocks tested on 13- and 17-year-old students (Allen, Carlson, & Zelenak, 1999). We collected baseline data, which included a pretest to measure Earth science content knowledge, in Year 0 (spring 2003 to fall 2003). The same Earth science content test was given as a posttest after student teaching in Year 1 (spring 2004 to fall 2004). We then planned and implemented a series of four workshops that focused on inquiry-based teaching and Earth science topics. Two sessions were implemented in the spring and two were implemented in the fall of Year 1. The purpose of the training sessions was to help study participants learn about science inquiry and to become familiar with the *Investigating Earth Systems* (*IES*) curriculum and the materials they would be using with students during student teaching.

In Year 0 (fall of 2003), preservice teachers worked on eight consecutive Saturdays in community-based settings to implement Earth science lessons with early childhood and elementary students. This setting allowed us to collect additional baseline data on the preservice teachers as they developed inquiry-based practices and pedagogical content knowledge. As part of their commitment to the study, the prospective teachers were required to teach an Earth science unit and allow the Earth Links staff to observe their lessons. We planned to observe participants as they student taught in Year 1: seven during the spring of 2004, and the remaining four participants during the fall of 2004.

We used the STIR (Bodzin & Beerer, 2003) to obtain process data during student teaching. The overall correlation coefficient of the STIR ($r = 0.580$) is not strong enough to justify its use as a self-assessment instrument. However, a perfect correlation ($r = 1.000$) between two raters established the STIR as an effective observational tool (Beerer & Bodzin, 2004). The STIR was used to rate participants in the Earth Links study on a scale of zero to four (0 = no inquiry; 4 = high inquiry) by the principal investigator (PI) and the project evaluator. Inter-rater reliability was 83%. Prospective teachers were rated in six categories to determine how inquiry-based their lessons were. The six categories are as follows:

1. Learners are engaged by scientifically oriented questions.
2. Learners plan investigations to gather evidence.
3. Learners give priority to evidence to draw conclusions and evaluate explanations.
4. Learners formulate conclusions and/or explanations from evidence to address scientifically oriented questions.
5. Learners evaluate their conclusions and/or explanations in light of alternative conclusions/explanations.
6. Learners communicate and justify their proposed conclusions. (Bodzin & Beerer, 2003, p. 41)

Finally, the PI kept fieldnotes to document all aspects of the study. Qualitative data in the form of fieldnotes, videotapes, and audiotapes were collected on the preservice teachers' instruction during both formal and informal school settings as well as on the number of students who were impacted by the Earth Links program. Descriptive data on the Year 1 cohort of 11 preservice teachers were obtained by averaging their pre/post content test scores and the STIR results. While these data are too sparse for quantitative analyses, they informed the research team about the study interventions and provided an impetus to conduct cross-case analyses (Leonard, Moore, & Spearman, 2007; Leonard & Oakley, 2006). Transcripts of videotaped science lessons were produced verbatim and analyzed using the Constant-Comparative Method (Glaser & Strauss, 1967). Given the limitations of this article, two cases are presented to learn about early childhood preservice teachers' inquiry-based practices and the influence of training sessions and the community-based internship.

Limitations

There are limitations relative to data collection and data analysis. First, the elapsed time between administrations of the pre/post content test may have been too long of a gap for preservice teachers to remember everything they had learned in the training sessions. Perhaps the posttest should have been given before and after student teaching to account for attrition. One preservice teacher was unable to take the posttest after student teaching and was therefore removed from the data analysis. Thus, the data reported became more scant as the Year 1 cohort of 11 preservice teachers was reduced to 10. Due to the small sample size, we present the quantitative data for descriptive purposes only.

The second limitation is the number of times we were logistically able to observe the preservice teachers' inquiry-based lessons. When it came to qualitative data collecting of this sort, we actually had too many preservice teachers to manage. During student teaching, the preservice teachers taught within an 80-mile radius. Schedules and logistics prevented us from videotaping multiple lessons for each student teacher in Year 1. Therefore, one Earth science lesson was observed, videotaped, and transcribed for each student teacher to learn about their inquiry-based practices. However, two of the 11 participants who did not student teach or allow us to videotape them were removed from the STIR analysis, bringing the number of observations to nine. Thus, the number of participants with both pre and post content scores and STIR observations was eight. Wherever possible, we do include all of the available data. While these data are sparse, collectively, they provided us with process data to inform our research with Year 2 cohort (spring 2005 to fall 2005). Thus, the data presented in this article are not to be generalized. The results demonstrate what was learned about the Year 1 cohort's inquiry-based practices given a specific context.

A third limitation was posed by the school itself. When we first began to observe the study participants, we learned that the schools were placing constraints (perceived and actual) on the preservice teachers. In one case, the science lesson was integrated with the language arts lesson because the preservice teacher was afraid to diverge from the school curriculum. To avoid this problem in future observations, the PI and graduate research assistant scheduled meetings with the school principal and the cooperating teacher. After explaining the research project, we informed them that each prospective teacher was required to teach a weeklong unit on Earth science. Two principals of suburban elementary schools expressed some concerns about the school curriculum, however. We were told that preservice teachers could not alter the science curriculum to teach Earth science. In one case, the principal allowed the participant to teach her lesson on Earth Day. In the other case, the individual, who happened to be one of our case study participants, was only permitted to teach a single lesson for us to observe. Therefore, both of these prospective teachers taught an isolated Earth science lesson rather than a unit.

Results

Prior to selecting the cases for further analyses, we examined the pre/post content tests and STIR ratings of the prospective teachers who participated in the study in Year 1. The results of the content test are shown in Table 1. The content test consisted of 11 items and was developed to assess the participants' general knowledge of Earth science and their ability to apply their knowledge of mathematics in context. A sample of four of these items is included in the Appendix of this article. Only ten participants completed both the pre- and posttest. The results of the pretest reveal that this cohort's content knowledge of Earth science was weak at the beginning of the program ($\underline{M}$ = 54.7). Posttest results show a modest gain of 7.2 ($\underline{M}$ = 61.9). While the mean posttest score was still relatively low, the range of the scores was robust (range of 64%), indicating that this cohort of preservice teachers had varied gains in Earth science content knowledge over the course of the study. Overall, the results show that three preservice teachers' posttest scores declined, two remained the same, and five increased. The largest decline on the posttest was nine points, and the largest gain was 46 points.

Table 1. Earth Science Content Test (*n* = 10)

Preservice Teacher ID#	Pretest Score (% Correct)	Posttest Score (% Correct)	Gain
9083	64	82	+18
1467	32	27	-5
5147	36	50	+14
4058	64	64	0
7338	50	41	-9
0440	45	91	+46
3394	64	73	+9
9955	64	64	0
9436	41	36	-5
7981	87	91	+4
Mean (*M*)	54.7 (SD 16.0)	61.9 (SD 21.7)	Net Gain +7.2

The results of the STIR are shown in Table 2. The results reveal preservice teachers' scores on the STIR ranged from a low average of 1.2 to a high average of 3.3. A score of 1.0 indicates teacher-centered or traditional instruction. In such settings, teachers exhibit a great deal of teacher talk and tend to have more structured "cookbook" lessons. A score of 3.0 indicates moderate use of inquiry-based practices. In this type of setting, teachers try to elicit student input and allow more autonomy in

Table 2. Year 1: STIR Results (*n* = 9)

Preservice Teacher ID#	1. Learners are engaged by scientifically oriented questions.	2. Learners plan investigations to gather evidence.	3. Learners give priority to evidence to draw conclusions and evaluate explanations.	4. Learners formulate conclusions and/or explanations from evidence to address scientifically oriented questions.	5. Learners evaluate their conclusions and/or explanations in light of alternative conclusions/ explanations.	6. Learners communicate and justify their proposed conclusions.	Average
9083[a]	1.0	3.0	3.0	0.0	0.0	0.0	1.2
1467[a]	1.0	1.0	3.0	2.0	2.0	1.0	1.7
5147[a]	1.0	1.0	2.0	2.0	3.0	2.0	1.8
4058[a]	1.0	2.0	2.0	2.0	3.0	2.0	2.0
2003[a]	1.0	1.0	3.0	4.0	3.0	2.0	2.3
7338[a]	1.0	2.0	3.0	3.0	3.0	4.0	2.7
0440[a]	4.0	2.0	4.0	3.0	2.0	2.0	2.8
3394[b]	3.0	3.0	4.0	4.0	4.0	2.0	3.3
9955[b]	3.0	2.0	3.0	4.0	4.0	4.0	3.3
Mean	1.8	1.9	3.0	2.7	2.7	2.1	2.3

Note: [a] Student taught in spring 2004. [b] Student taught in fall 2004.

the teaching-learning process. The data also reveal this cohort's strengths and weaknesses across the six categories of the STIR. The cohort was strongest in Category 3 (M = 3.0), "Learners give priority to evidence to draw conclusions and evaluate explanations." However, they were weakest in Category 1 (*M* = 1.8), "Learners are engaged by scientifically oriented questions." Overall, the data show mixed results as half of the participants exhibited student-centered practices and the other half exhibited teacher-centered practices. As shown in Table 3, however, these data do not correlate very well with the content knowledge test. Thus, it appears that content knowledge did not factor into this cohort's ability to engage students in science inquiry.

Table 3. Comparison of Inquiry-Based Practices and Earth Science Content Knowledge (*n* = 8)

Preservice Teacher ID#	STIR Rating	Posttest Score	Pre/Post Gain
9083	1.2	82	+18
1467	1.7	27	-5
5147	1.8	50	+14
4058	2.0	64	0
7338	2.7	41	-9
0440	2.8	91	+46
3394	3.3	73	+9
9955	3.3	64	0

In order to examine this idea further, we selected two preservice teachers for further study. The two participants who emerged as candidates for case studies were Hannah (Preservice Teacher ID# 0440) and Cora (Preservice Teacher ID# 7338). They were good candidates for cross-case analysis because they had similar overall scores on the STIR (Hannah: *M* = 2.8; Cora: *M* = 2.7) and both student taught in the primary grades during the spring of 2004. Hannah taught in a 1st-grade classroom in an urban setting, and Cora student taught in a 2nd-grade classroom in a suburban setting. We believed a cross-case analysis of their inquiry-based instruction would further inform our study about the complexities related to teacher training and enactment of inquiry-based practices. Given the limited number of studies about early childhood teachers, these cases serve to inform the education and research community.

Teaching episodes are presented next to more closely examine Hannah and Cora's science teaching and inquiry-based practices. The numbers next to the names indicate the places in each lesson where the teaching episodes begin and end. Since our focus is on the preservice teachers' practices instead of the students' learning, we chose not to identify students by name or gender.

Hannah's Lesson: Folds and Faults

Hannah was a 23-year-old, African-American female. She had the highest gain score on the Earth science content test (+46). Hannah taught 21 1st-grade African-American students (13 girls and eight boys) in an urban elementary school. Her Earth science lesson, "Folds and Faults" (1996) came from the Internet. Having previously taught this lesson to students in the community-based setting, the objective of the lesson was for students to learn about the Earth's crust and how the layers moved to create folds and faults. Hannah began by developing a KWL chart (what students know, what they want to know, and what they learned). Then she brainstormed with students about different types of layers to help them understand how rocks were formed. Next, she introduced the students to the vocabulary they needed to know and told them they would pretend to be scientists. She distributed PLAY-DOH, which was provided by Earth Links staff. The students used the PLAY-DOH to simulate the layers of the Earth's crust. First, students flattened four different colors of PLAY-DOH and stacked them vertically to represent layered rock. Then, students sliced cross-sections of the compressed "rock" to observe the layers. Hannah's STIR rating for this lesson was 2.8.

Teaching Episode 1

21 Hannah: *I want you to tell me what you want to know about rocks.*

22 Student: *Do they grow?*

23 Hannah: *That's interesting. Do rocks grow?*

24 Student: *Do they break?*

25 Hannah: *Okay, good. Can rocks break? Okay, I'll take two more hands.*

26 Student: *Can you move rocks?*

27 Hannah: *Can you move rocks? What do you think? If you went outside and you saw a rock, do you think you could move it?*

28 Student: *Yeah.*

29 Hannah: *So we can answer that question with yes. We can move rocks. Can we move all rocks?*

30 Student: *No, because some are big and heavy and stuck on the ground.*

31 Hannah: *[Do] you have another question about rocks?*

32 Student: *How do rocks grow?*

33 Hannah: *Okay, we have that question up on the board already. This is what we're going to do. Since you already know that rocks can be gray, they can be big or small, they have layers, and you want to know whether rocks can grow and can rocks break, today we're going to end up answering "Can rocks break?" when we do our activity. But since you already know that rocks have layers, I want you to put your thinking caps on real tight. What are some other things you know of that have layers?*

34 Student: *Cake.*

35 Student: *A sandwich.*

36 Hannah: *Good, a sandwich. What are the layers of a sandwich?*

37 Student: *Meat.*

38 Student: *Pickles.*

39 Student: *Tomatoes.*

40 Student: *Bread.*

41 Student: *Cheese.*

42 Hannah: *Good, those are all different layers of a sandwich. So we have cake, a sandwich. What are other things that have layers?*

43 Student: *Lettuce.*

44 Hannah: *Lettuce. How do you know that it has layers?*

45 Student: *You can keep pulling the lettuce off and there is more underneath of the other layers.*

46 Hannah: *This is what we're going to do today. We're going to study rock layers. There is a special word for that, and it's a really big word. It is called stratigraphy. Can everybody say that?*

47 Class: *Stratigraphy.*

48 Hannah: *Stratigraphy is the study of rock layers. Today, we're all going to be scientists. If you think that's cool, then I want to see you do the silent cheer.*

49 [Students raise their fists in the air.]

Analysis of Teaching Episode 1

Hannah's lesson can be described as structured inquiry because the students investigated rock layers using a prescribed procedure (Windschitl, 2003). The data presented in Teaching Episode 1 clearly show that Hannah understood what inquiry was and how to implement it. She provided her 1st graders with the opportunity to formulate questions using the KWL procedure. In fact, she was the only preservice teacher to do this among those who we observed during student teaching. As a result, she received a perfect score of 4.0 on the STIR in Category 1, "Learners are engaged by scientifically oriented questions." Moreover, she exhibited strong PCK as she began her lesson and explored student interests.

Hannah did not teach this lesson in isolation. Instead, she focused on building and constructing student knowledge about rocks in a unit. Hannah exhibited strong questioning techniques, and she encouraged students to make connections between rock layers and objects in everyday life. Furthermore, she asked students to explain and justify their answers to the questions (e.g., line 44). When Hannah introduced students to new vocabulary (e.g., *stratigraphy*) in line 46, she explained what the term meant, which showed depth of content knowledge. Use of science vocabulary, no doubt, helps to entrench one's own knowledge and understanding of concepts (Dickerson et al., 2001). Then, Hannah peaked the students' interest and motivation by telling them they would assume the role of a scientist. The response was unanimous as Hannah guided the children in the direction she wanted them to go by giving them autonomy and letting them make real-world connections.

Teaching Episode 2

55 Hannah: *Okay, now everyone have a seat. Whether you are done or not done, have a seat. This is what I want you to do next. Look at your PLAY-DOH; here is mine. Somebody raise your hand and tell me how many different layers of PLAY-DOH we have.*

56 Student: *Four.*

57 Hannah: *We have four different layers. Now I have a question for you. If this was a rock, look at your rock and tell me, which layer would be the oldest?*

58 Student: *The yellow one.*

59 Hannah: *Okay, where is the yellow one on yours?*

60 Student: *On the bottom.*

61 Hannah: *She said the yellow one is on the bottom, so she thinks it's the oldest. Raise your hand if you think she is correct. Now, tell me, why is this layer the oldest?*

62 Student: *Because it was the first one there.*

63 Hannah: *Excellent, it was the first one there, so it's the oldest and on the bottom. So, if that's the oldest and on the bottom, then what do you think the top one is?*

64 Student: *The youngest.*

65 Hannah: *It's the youngest. And why?*

66 Student: *It was the last one there.*

67 Hannah: *It was the last one placed there, good. So just like the rocks you see outside, the older layers will be on the bottom because they were placed there first. So if you're outside, and the rocks that were here from a long, long time ago, those rocks would be on the . . .*

68 Student: *Bottom.*

69 Hannah: *And the rocks that were kind of recent, probably around when we were little, those rocks would be on the . . .*

70 Student: *Bottom.*

71 Hannah: *On the bottom?*

72 Student: *On the top.*

73 Hannah: *Good, on the top. I want you to look at your PLAY-DOH, which we are pretending are rock layers. I want you to draw how it looks, and I'll give you some crayons so you can put the right colors on. Everybody look up. You should be able to view each rock layer from the top and from the side. Draw what you see from the top.*

74 [Students draw and label worksheets.]

Analysis of Teaching Episode 2

After students reviewed the four layers of the Earth's crust and cross-cut PLAY-DOH samples, this discourse emerged between Hannah and the students. The discourse reveals that Hannah gave her students the autonomy to layer their rock samples using whatever color scheme they chose (see line 59). However, rather than limiting the discussion to simply talking about the layers, Hannah pushed the students' understanding about the age of the layers. Time is a huge factor in the rock cycle. Rock is not formed overnight; the process takes many years. Hannah asked appropriate questions to get at this knowledge: "Which layer would be the oldest?" (line 57); "Why is this layer the oldest?" (line 61); "What do you think the top one is?" (line 63); and "Why?" (line 65). Students based their claims on personal experiences and evidence (line 66) and affirmed one another with nonverbal cues (line 61). Thus, Hannah also received a perfect 4.0 on the STIR in Category 3: "Learners give priority to evidence to draw conclusions and evaluate explanations." Finally, the students drew topical maps of the artifacts they created in this lesson. Thus, these urban 1st-grade students shared in the teaching-learning process alongside Hannah, who facilitated authentic learning, rather than teaching by telling, which exemplifies inquiry-based instruction.

Cora's Lesson: Surface Tension of Water

Cora was a 40-year-old White female. She had the largest decline on the Earth Science content test (-9). However, her rating on the STIR ($\underline{M}$ = 2.7) indicated moderate use of inquiry-based practices. She student taught in a 2nd-grade class with 21 students (11 boys and 10 girls; one Asian, 19 White, and one other) in a suburban school district. The science lesson that she presented came from the *IES* (2001) curriculum. The objective of the lesson was for students to learn that water had surface tension. Three different activities were provided for students: (1) boat ride, (2) nickel drop, and (3) penny spill. For the boat ride, a piece of paper was placed in a tub of water. Then, a drop of liquid soap was released near the piece of paper, causing the paper to move forward across the water. In the second activity, students used an eyedropper to put water onto a nickel while keeping count to determine how many drops it took before the water ran off. In the third activity, students dropped pennies into a bowl of water until the water spilled over. They also kept a record of the number of pennies needed for the spill to occur. Thus, mathematics in the form of data collection and analysis (i.e., tallying) was integrated with this science lesson. Three teaching episodes are presented next which describe a whole-group discussion, a small-group instruction, and another whole-group discussion during this lesson.

Teaching Episode 3

88 Cora: *Did you know that the top layer of all water is really like a skin? It's like a stretchy skin. That's pretty cool, isn't it? And in scientific language, we have a name for it. And that's what these experiments are going to be about today. Does anyone know what that word is? [Name]?*

89 Student: *Um . . . I can't pronounce it.*

90 Cora: *Oh, but you're a smart girl. How did you know? Where did you look to get the answer?*

91 Student: *At the top of the paper.*

92 Cora: *You are so smart. Who wants to give a shot at pronouncing it? Any brave person? [Name]?*

93 Student: *Tension.*

94 Cora: *That's one part of it. What's the first word?*

95 Student: *Surface.*

96 Cora: *Good. So this is what each experiment you do today is going to be about. We're going to talk more about it after the experiments start. Right now, we're going to get started. Here's how it's going to work. I'll tell you the names of your groups, and then we're going to get started. You'll do each activity for about 15 minutes, and there's someone at each table to help you perform these experiments. You're going to be performing the experiment and making some predictions, writing down what you've seen, then drawing a picture. Even though the experiments are different, you'll be doing the same steps for each experiment, and there will be somebody there to help you. So let's get started. The first group will start at Mrs. A's table, the nickel drop, right over here.* [Calls out names.] *If you need more chairs, pull one from around the room. The next group is going to Mrs. E's table.* [Calls out names.] *Everybody else is going to stay here.*

Analysis of Teaching Episode 3

Cora's lesson came from the *IES* curriculum, and to our knowledge, she had not previously taught the lesson. Furthermore, we knew from conversations we had with Cora before the observation that it was an isolated lesson and was not taught as a unit. The school's curriculum was very tight, and Cora did not have a great deal of flexibility to alter the curriculum. As previously stated in the "Limitations" section, to fulfill her commitment to the research study, the principal permitted Cora to teach a single science lesson for the research team to observe. While the decision placed tremendous constraints on Cora and the study, we agreed to the conditions.

Yet, what is striking about this lesson is the amount of support Cora had from the cooperating teacher and parents. Two parents volunteered to help with the lesson by working alongside students at one of the centers while Cora worked with the students on the boat ride activity. Thus, a great deal of preparation and planning occurred prior to the lesson presentation.

At the outset, Cora introduced the vocabulary related to the activities: *surface tension*. However, she did not explain what the term meant nor did she allow students to list examples of surface tension in their everyday experiences such as diving into a swimming pool. She simply stated, "So this is what each experiment you do today is going to be about" (line 96). However, Cora did allow students to make predictions, observations, and drawings, which are critical aspects of the scientific method. Cora's lesson is also an example of structured inquiry since she specified exactly what questions students would answer and exactly how they would carry out each of the activities (Windschitl, 2003).

Teaching Episode 4

99 Cora: *Now the first thing we should do is turn to the boat ride page. Every good scientist starts their experiment with a question. Stop and think about this for a second. We'll have a pan of water, and we're going to take this piece of paper and put it in the water. These are the questions we need to answer: "Do you think the boat will sink?," "Do you think the boat will flip over?," "Do you think the boat will go forward?," or "Do you think the boat will go backwards?" You don't know, that's why it's called a prediction because you have to guess. So think about what's going to happen and take a guess. What do you think? It's okay to be wrong in your guess, this is science. Write down your predictions.*

100 [Students write down predictions on papers.]

101 Cora: *Okay, guys, we are ready. We're going to put this boat in the water and put a drop of dish detergent on the back end of it. And we have our four choices: the boat will sink, the boat will flip over, the boat will go forward, or the boat will go backwards. Let's try it.*

102 [Cora performs experiment, and the boat moves forward.]

103 Students: [Cheers.] *Do it again! Do it again!*

104 Student: *Put more on; make it go faster.*

105 Cora: *That's interesting. Some of you have said the more soap you put on it, the slower it will go, and you think if we put more on it, the boat will go faster. Let's try it.*

106 [Cora performs experiment again.]

107 Cora: *It's not moving. Why do you think that is? Try putting more on again.*

108 [Student performs experiment.]

109 Cora: *Once there is soap in the water, the boat won't go. The soap breaks up the surface tension. We need to get fresh water in it to do it again. Go to your next page, and now you have to write down all your observations. What's an observation? What did you see and what did you do when I was doing the experiment? You were watching; you were observing. To observe means to watch. That's what you're writing down—what you've seen.*

Analysis of Teaching Episode 4

The boat ride activity was a very exciting and interesting activity as noted by the students' exclamations (see lines 103 and 104). It should be noted, however, that this activity was a demonstration instead of an actual student investigation like the nickel drop and the penny spill. Logistically, working with large bowls of water could have been difficult for students. However, Cora could have had student volunteers add the soap or drop the boat in the water. Thus, she exhibited a great deal of control over this activity. Nevertheless, she conducted the investigation twice to test the students' predictions, stating "Let's try it" (lines 101 and 105); and "The soap breaks up the surface tension" (line 109). Finally, she instructs the students to write down what they observed. At this juncture, it is not clear whether students clearly understand what surface tension is. Their voices are missing from the dialogue because Cora conducted the boat ride activity instead of allowing the students to actively participate. Thus, she received a STIR score of 1.0 in Category 1: "Learners are engaged by scientifically oriented questions."

Since the students rotated among the three centers, Cora got a chance to reteach the boat ride lesson two more times. The second time around, she did not change the water or use a different piece of paper for the boat, and the boat sank. Then, she changed the water but used the same piece of paper, and the results were the same. The third time around, Cora changed the water and used a different piece of paper. On the first trial, the boat also sank; but on the second trial, it moved forward across the water. Cora used the failed trials to justify why scientists perform experiments more than once before drawing conclusions. To summarize the boat ride lesson, Cora called the students back together in a whole group. After eliciting key elements of the scientific method from the children (i.e., form question, predict, and observe), Cora reviewed the results of the boat ride lesson. The science discourse that emerged is presented below.

Teaching Episode 5

163 Cora: *What happened with the boat ride? The first time we did it, it worked well right? What about the second and third groups when we did them the first time? It sunk right? What we learned about today is something they're learning in 4th and 5th grade. What was the scientific term for what we learned today?*

164 Student: *Surface tension.*

165 Cora: *Anybody want to take a guess at what surface tension is? [Name]?*

166 Student: *Top of the water.*

167 Cora: *Right, and what about this skin on top of the water?*

168 Student: *It sticks together.*

169 Cora: *And it does what [Name]?*

170 Student: *When you put soap in it, molecules break apart and the boat pushes forward.*

171 Cora: *Right, that was a good word, molecules. When I was preparing this lesson, I didn't use the word molecules because I thought everybody would be confused. So, instead of saying molecules, I said they were very tiny water drops. So, good job, [Name], for knowing that. There are just a couple things we want to wrap up. We learned what scientists do, we talked about surface tension, we talked about the boat experiment and the soap breaking the skin on top of the water. So what are we going to tell our parents we learned about today?*

172 Student: *Surface tension.*

173 Cora: *Very good. Do you think you know how to perform an experiment?*

174 Student: *Yeah.*

175 Cora: *Well, great job today, everyone.*

Analysis of Teaching Episode 5

During the whole-group discussion, Cora tried to ensure that all of the students understood surface tension. When she probed the students, it was evident that this concept was still a bit fuzzy. In line 166, one student responded, "Top of the water." This student focused on the surface part of the definition since *top* and *surface* are synonymous terms. Then, a second student responded, "It sticks together" (line 168). This student tried to articulate the *tension* part of the term. Sticking together implies putting forth resistance. Finally, a third student described what happened to water surface tension during the investigation: "When you put soap in it, molecules break apart, and the boat pushes forward" (line 170). While this student understood that molecules break apart, there was still no clear definition put forward about surface tension as resistance to pressure. Nevertheless, it is clear that Cora helped the students form appropriate conclusions. Thus, Cora received a STIR score of 3.0 in Categories 3, 4, and 5 (see Table 2). Moreover, students recorded their data and observations on data sheets using their own words or by drawing pictures. Therefore, Cora earned a perfect 4.0 on the STIR in Category 6: "Learners communicate and justify their proposed conclusions." Cora did, however, exhibit weak PCK in this science lesson. She underestimated these 2nd graders' ability to understand appropriate science vocabulary such as *molecules*, *resistance*, and *pressure*. Thus, her enactment of inquiry-based instruction was weakened by her inability to define what surface tension was and by not connecting it to real-world experiences.

Cross-Case Analysis

In order to compare and contrast each of the foregoing cases, we analyzed differences and similarities among these individuals as well as the setting in which they taught. One obvious individual difference is age. Yet, while Cora was older than Hannah, they both received similar training in science and mathematics methods courses and had the opportunity to take the same science content courses. Another difference is race. Hannah was African American, and Cora was European American. While racial differences among the participants are not the focus of this paper, it should be noted that racial background might have impacted the setting these two prospective teachers chose for student teaching.

The settings where Hannah and Cora student taught were quite different. Hannah taught at an urban school with predominantly African-American students. While she did not have as much parental support as Cora, she had the flexibility to teach an entire unit on the rock cycle. Because of this, Hannah learned more content and understood the vocabulary she was teaching. Furthermore, she had taught the lesson previously during the community-based internship. Thus, she was familiar with the lesson and could learn from prior mistakes and reflection. Cora, on the other hand, student taught in an affluent, predominantly White suburban school. She had parental support and all of the materials and supplies needed to carry out an inquiry-based lesson with predominantly White students; however, she did not have the flexibility to delve into the content for more than a day. Thus, she was not able to develop deep content knowledge about surface tension. While she had worked with young learners during the community-based internship on the water cycle, she did not present the same lesson on surface tension. Overall, she exhibited weak content knowledge and PCK. It is important for teachers to engage in inquiry-based practices themselves in order to teach science inquiry to students (Dickerson et al., 2007). Thus, the social context either supported or inhibited Hannah and Cora's inquiry-based practices.

Given their limited experience, neither teacher was able to engage their students in guided or open inquiry. Perhaps, such goals are unrealistic for primary teachers, considering secondary teachers have difficulty enacting open inquiry in secondary science classrooms (Windschitl, 2003). However, the most notable difference between Hannah and Cora was that Cora focused primarily on the processes of inquiry while Hannah focused on both orientation and processes (Bianchini & Colburn, 2000). Their conception of inquiry seemed to define their practice. While Hannah and Cora had different levels of experience in field-based settings and different degrees of background knowledge, as evidenced by their Earth science content scores and the teaching episodes, we learned that teacher conceptions are just as important as content knowledge.

Discussion

One of the findings of this study is the stark difference in content knowledge exhibited by study participants after the training sessions and community-based internships. Data analyses show a modest increase in scores, but the results are mixed since four prospective teachers' scores remained the same or decreased and four increased. These process data were informative, however. To ensure that Earth science content knowledge would be stressed in future training sessions, we decided to hire scientists and science educators as consultants to teach the training sessions in Year 2 of the study and provided incentives for Year 2 cohort participants to take a tuition free, field-based Earth science course.

The second finding was that different degrees of background and content knowledge did not appear to map consistently with STIR ratings. Half of the cohort engaged in student-centered (inquiry-based) behaviors, and the other half engaged in a range of teacher-centered (non-inquiry-based) behaviors. There was no apparent correlation between content knowledge scores and STIR scores, however. Participants with high STIR scores had low Earth science content scores and vice versa. Thus, the impact of the intervention on inquiry-based practices is also mixed.

When the classroom discourse in each of the teaching episodes was analyzed using the Constant-Comparative Method (Glaser & Strauss, 1967), we learned that both Hannah and Cora engaged students in structured inquiry but enacted science inquiry in different ways. Thus, the third finding is that prospective teachers' conceptions of inquiry influenced their inquiry-based practices. While content is important, conceptions are also important because they influence PCK (Mellado, 1998). Primary teachers can learn the specific content needed to teach a lesson but fail to explain it in terms that make sense to students. Thus, models are needed to show prospective teachers exactly what inquiry-based instruction looks like in practice (Yoon et al., 2006). Appropriate field-based experiences are needed to practice inquiry-based pedagogy in non-threatening and nurturing environments such as community-based settings, camps, clubs, and after-school programs (Wilson, 1996). While this finding cannot be substantiated with a cross-case analysis of two prospective teachers, we decided to emphasize both aspects of inquiry (orientation and processes) with the Year 2 cohort.

The fourth finding is that the learning environment influenced the implementation of inquiry-based practices. From field observations and student-teacher feedback, we learned that teaching science was on the back burner at some elementary schools. Furthermore, when preservice teachers were able to teach science lessons, school constraints caused some cooperating teachers to limit preservice teachers' instruction to teaching on Earth Day in one case or to presenting an isolated lesson such as the one Cora taught. Thus, there appears to be a mismatch between what is taught in teacher preparation programs and what actually occurs in school settings when it comes to science instruction. Thus, sustaining inquiry-based practices among early childhood/elementary preservice teachers requires a supportive educational environment that values inquiry-based instruction and authentic science investigations to help children learn the processes and methods of science in everyday classrooms. At the end of the Year 1 study, we reemphasized the goals of the Earth Links program with principals and cooperating teachers to ensure that participants in the Year 2 cohort had the opportunity to engage students in an Earth science unit rather than isolated science lessons.

Conclusion

Reform-based instruction, such as facilitating science inquiry in primary classrooms, is a complex enterprise. Researchers must be cognizant of the conceptions prospective teachers have about inquiry prior to attempting to influence their practices (Mellado, 1998). Many primary teachers have limited science exposure, especially in Earth science. Therefore, a field-based Earth science course that enhances their ability to engage in the orientation and processes of inquiry may be more beneficial than a few one- to two-hour workshops in a given year. Finally, the school environment, where prospective teachers are expected to implement what was learned in teacher preparation programs, either supports or inhibits prospective teachers' inquiry-based practices (Bianchini & Cavazos, 2007; Crawford, 2007). Differences in institutional support appeared to influence two prospective teachers' enactment of science inquiry. If schools place science on the back burner or if the curriculum is too rigid for inquiry to flourish, then prospective teachers will find it impossible to sustain inquiry-based practices learned in teacher preparation programs.

Our work is ongoing. Given the mixed results of this study, we intend to offer an Earth science course and to attend to conceptual understanding of inquiry with participants recruited for the Year 2 cohort and study the results. In order to impact student outcomes in science, we must attend to teachers' ability to engage students in authentic scientific tasks and science inquiry. However, the settings in which prospective teachers practice inquiry-based instruction are crucial to sustaining such practice. Thus, we conclude that appropriate conceptions, student-centered practices, and supportive environments are prerequisite to sustaining prospective teachers' inquiry-based practices during induction.

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Appendix

Sample Items: Earth Science Content Test

1. An earthquake on the sea floor can produce
   a. magma.
   b. subduction.
   c. tsunamis.
   d. tornadoes.

2. If you go outside on a sunny day, you will make a shadow. At some times of day, your shadow is longer than you are. At other times of the day, it is shorter than you are. How can this difference in the length of your shadow be explained? (You can use a drawing to help explain your answer.)

3. If you measured your shadow at noon during the summer and at noon during the winter, would the measurements be the same or would they be different? Briefly explain your answer.

4. New crust is formed and spreads apart at
   a. transform fault boundaries.
   b. convergent plate boundaries.
   c. subduction zones.
   d. divergent plate boundaries.

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