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ABSTRACT

A major goal of any teacher education program is to prepare prospective teachers to know what to do in a classroom of children and how to do it effectively. The purpose of this research study was to examine the level of first-year teachers' science content knowledge, pedagogical knowledge, and pedagogical content knowledge in order to evaluate the effectiveness of a teacher preparation program for elementary education majors with science as their area of concentration, developed as part of the Quality University Elementary Science Teaching (QUEST) Project at Indiana University. Four elementary education graduates in their first year of teaching constituted the sample for this investigation. Data collection methods included observations, interviews, self-evaluations, surveys, and document analysis. Results indicate that all the novice teachers interpreted the interdisciplinary nature of science as the integration of science with other subject areas rather than across the science disciplines. Each of the teachers supported the notion of science as inquiry during interviews and surveys, however, only one showed any true evidence of its practice in the classroom. Other findings include: none of the teachers utilized innovative teaching strategies and the teachers' overall content knowledge appears to increase with more science content courses completed. Contains 25 references. (JRH)

The First Year of Teaching: Science in the Elementary School

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Introduction

A major goal of any teacher education program is to prepare prospective teachers who know what to do in a classroom of children and how to do it effectively. Borko and Livingston (1989) refer to this process as developing pedagogical expertise. They recommend that in order to improve, teacher education programs must examine the acquisition of expertise by their students. This expertise involves theoretical knowledge as well as practical knowledge.

Teachers must possess a specialized understanding of the subject matter they are expected to teach in addition to a personal understanding of the content (Wilson, Shulman, & Richert, 1987). Smith and Neale (1989) contend that while science teachers must have correct substantive content knowledge, they must have the ability to translate that knowledge into classroom teaching. This may be especially difficult to achieve with prospective elementary teachers as research continues to reveal that they misunderstand fundamental science concepts and may not reason at the level required for problem solving (Ginns & Watters, 1995).

Learning to plan lessons and developing successful teaching strategies is a slow process. "Prospective science teachers . . . have few of their own resources and teaching experiences to draw on" (Tippins, Kagan, & Jackson, 1993, p. 63). The pedagogical knowledge base develops after years of preparation and extensive experience in the classroom (Clermont, Borko, & Krajcik, 1994). Ultimately, elementary teachers must have a considerable knowledge base of each of the sciences (Grossman, Wilson, & Shulman, 1989; Lederman & Latz, 1993), and they must possess a repertoire of pedagogical skills from which they can select the most appropriate way of presenting particular science concepts to children (Magnusson & Krajcik, 1993; McDiarmid, Ball, & Anderson, 1989; Shulman, 1986; Shulman, 1987).

To compensate for the rather unrealistic expectation that all elementary teachers will demonstrate expertise in science, Abell (1990) made a case for the elementary science specialist: "a person who has chosen to major in science at the undergraduate level and has received the concomitant professional training for teaching elementary science" (p. 293). Preparing some preservice elementary teachers as science specialists, while providing a fundamental science education to all preservice teachers, seems a more realistic expectation of university teacher education programs.

The purpose of this research study was to examine the level of first-year teachers' science content knowledge, pedagogical knowledge, and pedagogical content knowledge. This evaluation was deemed important in determining the effectiveness of a new teacher preparation program for elementary education majors with science as their area of concentration, developed as part of the Quality University Elementary Science Teaching (QUEST) Project at Indiana University. The science concentration students, called QUEST students, take additional credit hours of science, work with children in a Saturday Science program, and enroll in a special section of the elementary science methods course. The final requirement of the concentration is completion of an interdisciplinary, laboratory science capstone course. Although those students who have selected the science area of concentration are not labeled as science specialists by the university or state, their level of preparation in science exceeds that of most students across the nation preparing to be elementary teachers. It is of interest to know how first-year teachers who completed the QUEST program differ from first-year teachers who had areas of concentration other than science. This investigation is an attempt to determine the QUEST program's effectiveness in preparing elementary teachers with appropriate content knowledge, pedagogical knowledge, and pedagogical content knowledge for the teaching of science.

Research Questions

1. What is the state of the first-year teachers' science content knowledge, pedagogical knowledge, and pedagogical content knowledge?

2. What differences in the three types of knowledge exist between first-year teachers with the science area of concentration and first-year teachers with other areas of concentration?

3. What changes in science content knowledge, pedagogical knowledge, and pedagogical content knowledge are exhibited by the first-year teachers as they have progressed from the university setting to the elementary classroom?

Methodology

Subjects

Four elementary education graduates in their first year of teaching constitute the sample for this investigation. The subjects were similar in that elementary education majors at this large midwestern research university must fulfill a minimum requirement of 12 hours of science content coursework. They must complete an introduction to scientific inquiry course and introductory level courses in biology, geology, and physics. Most students choose to enroll in the biology and physics courses specifically designed for elementary educators. These students are also required to take an elementary science methods course. The scientific inquiry, biology, physics, and methods courses were all revised in accordance with the goals of the QUEST Project to improve and update science education at Indiana University. Therefore, all elementary education majors had multiple opportunities to benefit from the many changes afforded by QUEST.

All preservice elementary teachers are required to complete 18 hours of coursework beyond the basic requirements in a content area of concentration of their choice (i.e., fine arts, language arts/humanities, mathematics, science, or social studies). The QUEST students take these hours in science and have the additional experiences mentioned previously.

The four subjects were selected from those recent graduates who had participated in earlier QUEST-related studies; who had secured a full-time, full-year teaching position; who were willing and able to allow the researchers into their classrooms; and whose school was within a reasonable driving distance from the university. All of the participating first-year teachers (3 females, 1 male) held elementary positions. As undergraduates, two of the elementary teachers had completed areas of concentration other than science. The two QUEST participants had completed an additional field experience in local middle schools, under the direction of specially prepared mentor teachers. This option, offered in conjunction with the capstone course, enabled them to become certified to teach at the middle school level.

Data Collection

Three of the four existing science courses for elementary education majors had been modified as part of the QUEST Project to include a greater emphasis on conceptual understanding of science content, increased use of an inquiry approach, and the use of technology in data collection and processing. The existing elementary science methods course also increased its emphasis on technological applications. Because science content knowledge, pedagogical knowledge, and pedagogical content knowledge are such vast areas, aspects of each type of knowledge that were specifically addressed in the teacher education program at this institution were examined. Evidence was sought in the areas below:

Science Content Knowledge
- science as interdisciplinary in nature
- science as inquiry
- subjects' scientific conceptions

Pedagogical Knowledge
- teaching science using the learning cycle approach
- social interaction in learning science
- building instruction on children's prior conceptions
- problem solving and higher level learning
- allowing children to structure their own learning

Pedagogical Content Knowledge
- applying appropriate pedagogy in teaching a concept to a group of children
- adapting college instruction to pedagogy appropriate at the elementary level
- applying appropriate technology in teaching a given concept.

Data were collected throughout the school year during three separate school visitations to each first-year teacher by one of the researchers. Given the nature of the study, a comparative case study design was employed to determine answers to the research questions (Bogdan & Biklen, 1992). To establish triangulation, multiple data sources were examined (Glesne & Peshkin, 1992). These methods include interviewing, observation, and document collection. During each on-site visit, interviews were conducted using a semi-structured protocol and audiotaped for later transcription and analysis. The participants were observed each time teaching a regular science lesson to their elementary students. One of the lessons was videotaped and the corresponding written lesson plan was collected for comparison to the lesson as presented. The teachers also assessed their own videotaped teaching performances. At the end of the semester, the first-year teachers completed four QUEST-developed instruments. Each of these instruments had been administered previously to all of them at least once during their teacher preparation program at the university. Therefore, some past data were available for comparison to consider the third research question. Table 1 provides a timeline of when the various data sources were administered during the teacher education program and the first year of teaching.

Qualitative Data

The qualitative data sources used in this investigation of first-year teachers are briefly described below.

Science Log A daily record of each science lesson: a) time period, b) the topic or title of the lesson, c) the type of instruction (i.e., hands-on activity and discussion, demonstration and discussion, or reading and discussion), and d) whether the lesson was integrated with any other curricular area; kept for 3-4 weeks preceding an on-site observation.

On-site Observation Descriptions of the teacher in action in the classroom, focusing on lesson presentation and management, interaction with students, classroom environment, etc.

Semi-structured Interview A set of questions presented verbally to the teachers covering their science content knowledge, pedagogical knowledge, and pedagogical content knowledge, allowing for some departure to clarify a respondent's comments.

Science Lesson Plan Participant-generated lesson plan or a series of science lesson plans on a self-selected topic.

Videotaped Teaching Videotaped recording of the teacher's presentation of one of the science lesson plans.

Video Self-assessment Semi-structured questions to guide the teacher's reflection of the lesson and its presentation after viewing the videotape.

Quantitative Data

The quantitative data sources used in this study are described below. The teachers' responses to the surveys provided qualitative information in addition to that culled from the sources listed in the section above.

Capstone Science Survey A Likert Scale questionnaire containing 24 items that assess each of the three types of knowledge (science content = 7, pedagogy = 10, and pedagogical content = 7). Statements are in a random order on the instrument, with the type of knowledge identifiers omitted.

Attitude Toward Self as Science Teacher A Likert Scale questionnaire consisting of 20 items that indicate the respondent's self-reflection as a science teacher.

Science Content Test A multiple-choice test of 10 items each in the areas of life science, earth science, physical science, and the nature of scientific inquiry.

Teaching Survey A 20-item Likert Scale questionnaire that measures a constructivist philosophy of teaching versus a more traditional perspective.

Results and Discussion

Individual results for those aspects of science content knowledge, pedagogical knowledge, and pedagogical content knowledge examined by the study are specifically addressed for each participant. Table 2 gives the averaged individual results for each administration of the quantitative instruments.

QUEST Teachers

Patty

Patty's first teaching position was at the third grade level in a public elementary school in a small town in south-central Illinois. There were approximately four self-contained classes of each of the K-4 grade levels in the school. In a school day lasting approximately five and one-half hours, Patty was expected to teach reading, language, spelling, mathematics, science, and physical education. Her additional responsibilities included frequent lunch, recess, and before/after school bus duties. The only free time available to Patty was 25 minutes in the morning when her 21 students attended music class.

Patty consistently displayed a positive attitude toward herself as a science teacher on the survey completed twice as a preservice teacher and again at the end of her first year of teaching (see Table 2). She seemed comfortable in the classroom, identifying patience and a strong academic background as her strengths as a teacher.

> I feel that I am a very calm person in the classroom and I can see that my students pick that up. . . . I think one of my other main strengths as a teacher is that I have a strong background in most of the subjects. I am a very strong math person, very strong science, and I feel that I am fairly strong in English skills (Interview 1, 11/94).

Science Content Knowledge. Patty demonstrated her understanding of the interdisciplinary nature of science by addressing life science, earth science, and environmental science concepts in an observed lesson focusing on the importance of soil. This was consistent with her agreement at each administration of the Capstone Science Survey with statements such as "The boundaries between the specific disciplines of science (chemistry, biology, physics, etc,) are not well defined."

Patty advanced from *agree* (on preservice administrations) to *undecided* (at the end of her first year of teaching) as her response to the Capstone Science Survey statement "Science is primarily a collection of facts about the universe that have been accumulated over time." This predilection for science facts was corroborated by her response to "What do you think science is all about?" She said, "I enjoy science. I enjoy watching the science documentaries. I really get into those" (Interview 1, 11/94). It should also be noted that Patty **missed** the greatest number of questions in the nature of scientific inquiry section of the Science Content Test.

Patty's performances on the Science Content Test were usually better than her peers (see Table 2), achieving 90% at the end of her first year of teaching, supporting her confidence in her science content knowledge. She rarely missed questions in the earth, life, and physical sciences. No conceptual inaccuracies were noted in Patty's written lesson plans or observed in her classroom presentations during the first-year of teaching.

Pedagogical Knowledge. In every interview, Patty emphasized the importance of inquiry in science and hands-on activities for the children. She stated that the best way for students to learn science was "by doing it, manipulating things, making their own reasons why things happen even if they are wrong, at least thinking about it. Touching it, doing it, changing it" (Interview 3, 4/95). She also said, "I think it's important that they know facts. . . . But I don't place too much emphasis on making sure that they have all of the facts" (Interview 3, 4/95). These verbal statements were contradicted by Patty's actions in the classroom. The three science logs she completed revealed that little or no hands-on science was being done in her classroom. Most of the entries listed reading and/or discussing the textbook. When questioned about this discrepancy, this novice teacher defended herself: "...in my district they're very strict upon sticking to the textbook. . . . Because they want the same thing going on in all of the schools at all of the grade levels. So we are very textbook-oriented" (Interview 1, 11/94).

When Patty was asked about teaching using an interdisciplinary approach, it was apparent that her definition was integrating other subject areas with science: "We tie in science and social studies a lot because we talk about different things that go on. . . . I tie in science in spelling. . . every third or fourth spelling list will be a complete science spelling list" (Interview 3, 4/95).

Although the learning cycle was emphasized during her teacher preparation and Patty supported its tenets on the Capstone Science Survey, she did not practice it. Patty admitted, "Rarely do I use hands-on materials to introduce a topic. Sometimes I do in math. But usually we do hands-on after the event. So I can have time to find things, pay for things, things like that." (Interview 3, 4/95). When asked about exploration, she responded:

> I spend probably a good third of my lesson in science talking about we are going to learn, what we think the chapter is about. I like to have the kids draw in personal experiences. . . . That keeps them interested, when they're allowed to talk about things that they can relate to it" (interview 2, 2/95).

Relating topics to the real world was Patty's application phase, however, it was usually accomplished through more discussion, rather than hands-on activities.

Patty consistently agreed with the Capstone Science Survey statement "Discussing what the children already know about the topic is a good way to begin a science lesson." Two of the observed lessons included lengthy class discussions. Patty seemed quite skilled at eliciting the children's prior knowledge.

> I think the teacher is there to find out what they know and to help them find out what they know. And then to help them take what they know and find out if their opinions are correct. Maybe they have some misconceptions that they need to rethink" (Interview 3, 4/95).

The children were quite involved in asking questions of their teacher and of each other. They frequently role-played and participated kinesthetically during science discussions.

On the Capstone Science Survey, Patty had agreed, as a preservice teacher, with the statement "Working in groups helps children learn science better than working independently." Her inservice response was, however, *undecided*. Patty encouraged social interaction in science, always pairing the students to read and review the textbook chapter, yet admitted that she did not often utilize cooperative group methods, except in art sessions.

She explained that her aversion to implementing cooperative groups in academic areas was a result of negative personal experiences throughout her schooling.

Patty's averages on the Teaching Survey (see Table 2) show that she leans toward a constructivist philosophy of teaching. Each time the Capstone Science Survey was administered, Patty agreed with the statement "Having children investigate science concepts using problem solving is more important than having them memorize scientific facts." However, problem solving was practically non-existent in her lessons. She attributed the absence to lack of time and lack of student ability. She struggled with such notions in the context of a real science classroom:

> I think it's important for the teacher to structure a lot of the content. But I do think it is important for the children to have choices within the structured system. Because from what I've seen, children take more responsibility when they have more decision-making in the process. . . . But there isn't much choice for them (Interview 2, 2/94).

When asked to describe a successful science class, Patty responded:

> When I have had my classroom running the way I want, I am standing over in the corner going, "Yes, this is happening finally." The kids are working. The noise level in the classroom is not atrocious, but yet there is some noise in the classroom. And I can kind of stand back and be quiet for a minute and things are still going on. They are still working. They are still talking with each other. They are still manipulating things or talking about ways of doing things" (Interview 3, 4/95).

Pedagogical Content Knowledge. During the first few months of the school year, Patty was committed to teaching science every day, for at least 30-45 minutes. She switched science sessions from the afternoon to the morning to make sure there was sufficient time for the lessons. Patty summarized her mission as a teacher of elementary science at the third grade level:

> I think it's important for the students by the end of the school year to understand processes used in experimentation, collecting data. I think it's neat if they understand *how to be* a scientist. Maybe they don't have the laws memorized, or the theories memorized. If they understand what science is all about, then I think that's a good start because they take that into fourth grade and start to really get into some good content" (Interview 1, 11/94).

But at the end of the year, she stated that her goal was to have science for at least four days a week.

Patty identified time as the greatest constraint she faced in her first year of teaching, stating that she could improve as a teacher by "Finding a way to get more time out of the six-hour day. . . . Because I am spending way too much time [outside of school]" (Interview 1, 11/94). Patty admitted that such a restriction directly affected her science teaching:

> There's a difference between what I think is most effective and what I actually do. The most effective way to teach science for me is hands-on. I have a lot of success when I do hands-on learning with my class. But I'll admit it's not what I do most often. Most often it's reading in our book. We do a few hands-on things. . . . I think it's just more the sense of me being overwhelmed, a first-year teacher trying to do all of the

different subjects. I don't have time to plan all of that" (Interview 2, 2/95).

But Patty also felt this was a hurdle she could eventually overcome:

> I think next year it is going to be better because I will have been through the book once. And instead of spending all of my time thinking about what is coming next, I can kind of - in the back of my mind - know what's coming next, know where we are going. And I will be able to spend more time getting things together to do hands-on. Thinking of different activities to do with science. I can't use the excuse that this school has no money, so I can't do hands-on science. Because that's not true. The school has no money and I don't have the time. But I think next year it will be a lot better because I'll have more time to spend getting those kinds of things ready for the kids. And I'll be more comfortable because I'll have been through the book once, too" (Interview 3, 4/95).

Summary. Patty was confident that she possesses adequate science content knowledge, pedagogical knowledge, and pedagogical content knowledge to teach science to elementary children. She verbalized the strengths of her abilities quite well and attributed the discrepancies observed in her practice to the constraints of school expectations and a general lack of time.

However, the disclosed discrepancies cannot be overlooked or easily explained away when evaluating the effectiveness of the QUEST program. During her undergraduate preparation, Patty had experienced and exhibited her agreement with or support of pedagogical techniques such as the learning cycle, cooperative learning, and problem solving. But in her inservice classroom practice, these were not observed. It is disappointing to see the devaluation of these techniques, especially with a strong emphasis on each during the QUEST program. Patty's commitment to putting into practice good science pedagogy is indeed questionable.

Nora

Nora taught fourth grade in a public elementary school in Northwestern Indiana. There were at least three classes at each grade level in the K-6 school. Nora was responsible for teaching science, mathematics, social studies, and reading/language arts in her self-contained classroom. She had free time when the students attended music, art, and physical education classes taught by other instructors. Nora identified discipline, science background, and rapport with the children as her strengths as a teacher.

At the beginning of the year, Nora was allowing herself "about a fifty-minute period of time for science. . . . just about every day" (Interview 1, 11/94). Her log for the month of October confirmed this, with entries for several hands-on activities. The later monthly logs revealed that entries for science lessons had been cut to an average of three days per week. The other two periods were used as computer lab time. Nora eventually conceded that "there is a lot to prepare" for science (Interview 3, 4/95).

Science Content Knowledge. The ostensible decrease in science time in this first-year teacher's classroom may have been in conjunction with Nora's observation that her students enjoy the interrelatedness of class topics:

> [T]hey're curious about a lot of things and because we are studying just such and such subject, I don't feel like that's the only thing you're actually studying. I think there's lots of things that tie into it and the kids pick up on that naturally (Interview 1, 11/94).

This beginning teacher broadened the interdisciplinary nature of science to include the other curricular areas. Nora regularly integrated science with math, social studies, and the language arts. Nora was apparently joined by the other fourth grade teachers in her enthusiasm for a science-centered curriculum. She declared, "If we had our way, we would take science and base everything else around it. We really would because the kids . . . love science, especially anything hands-on science" (Interview 2, 2/95).

Science as inquiry was a quite important issue for Nora. She emphasized "doing" science in the classroom by providing hands-on activities and encouraging her students to investigate topics they found interesting.

> I want them to understand . . . [a] lot about the scientific method. I want them to be able to think and infer, do a lot of inferring - just because it's not laid out for you. I want them to be thinking. . . . Sometimes it's important to know things and to be able to list them. But in the end, if I can get them to be thinking higher - on a higher level - and know a scientific method and enjoy science when they leave here, that would be goal enough for me. That would make me happy (Interview 1, 11/94).

Nora seemed to follow through with these goals. Throughout the year, her students completed inquiry projects on a wide variety of topics. She emphasized hypothesis testing with numerous opportunities for collecting data. Most of the time, the children's written reports of activities and experiments served as their language arts assignments. Learning to graph data properly was also integrated well with math lessons.

Nora admitted that she was weak in some science content areas, as the results on the Science Content Test revealed (see Table 2). However, she regarded teaching unfamiliar or difficult topics as challenges that were her responsibility to meet. When asked how she handles teaching a science concept that she doesn't understand very well, Nora replied, "I make sure I know it because I can't teach it unless I'm fairly comfortable with it. I can't do it. . . . I don't skip over it, because it bothers me too much (Interview 1, 11/94).

Pedagogical Knowledge. Nora's lack of support for the learning cycle approach to teaching science to children, as seen in her responses to the Capstone Science Survey, continued into her classroom. She could not identify the phases of the learning cycle when interviewed. Nora explained her typical science teaching strategy:

> First we talk about what they'll need to accomplish . . . when I define the goals that they'll be looking at. . . . There's exploring time going on while they are trying to do their work. Just kind of naturally on their own, because that's what they want to do (Interview 2, 2/95).

It was then that she began to reconsider her usual lesson format by musing aloud, "Maybe that should tell me something where maybe I should give them time to do that before we start into it. Then maybe they'd be more curious about what it is" (Interview 2, 2/95).

Although she admits to not using formal cooperative group learning techniques during science lessons, Nora encourages social interaction in learning science:

> I don't think I've ever had them when they're just working alone. For one thing, it's because of supplies. And second of all, I think it's better when they have someone there for them anyway, if they have a question to ask each other (Interview 1, 11/94).

Nora stated that working in cooperative groups seems to go more smoothly when no shared materials are involved, "Unless you have one [object] for each person, it's very frustrating" (Interview 2, 2/95). She was consistent throughout this first year of teaching, remarking during the final interview, "I think it's better to have them work with their peers and to work with one another and to talk things out together. The majority of time we do do that" (Interview 3, 4/95).

Eliciting the children's prior knowledge of a concept was evident in each of the observed science lessons Nora taught. She was genuinely attentive to the students' comments and ideas. Nora elaborated on this point:

> I really try to encourage the kids to bring things from outside at home, or from outside. . . bring their experiences into the classroom. I'm really pushing for that with prior knowledge and life experiences, in general, to tie that into any of their learning. Because I catch their attention better that way (Interview 1, 11/94).

What the students revealed in their class discussions did impact on how a lesson progressed. Nora gave the following example from a unit on plants:

> We discussed the parts of the flower, the pistil and the stamen. Part of it was review from third grade, but a lot of them didn't know it. They only saw it in a book, so I brought in fresh flowers for them to see. Then we talked about inside the ovary, inside the flower. We split it open so they learned to use the microscope [too] (Interview 1, 11/94).

Nora's respect for her students was overwhelmingly obvious. It was also apparent in her concern that the children structure their own learning. However, Nora expressed her difficulty with making student choice a continually viable option in her fourth grade classroom.

> If I let them make some of their own decisions and choose what they would like to study, they always like it a lot better and it means more to them. . . . Then it's always a matter of how am I able to get everything in that I need to get in. . . . The reality for that is there would be too many things juggling all at one time. . . . It actually frustrates the heck out of me (Interview 2, 2/95).

Pedagogical Content Knowledge. Current events played a major role in providing teachable moments for Nora's elementary students. On planning for science instruction, she commented:

> I don't go in the order of anything. . . . [W]hen the earthquake hit Kobe, Japan, we studied earthquakes. We had newspaper articles and . . . we just brought it in with a little bit of geology and worked with some clay - did shifting plates and . . . why the earthquake (Interview 2, 2/95).

About being a first-year teacher of elementary science, Nora was quite positive in her direct comments, "I enjoy teaching science. I am enjoying it more and more, and I am learning right along with these kids which usually happens a lot in teaching anyway" (Interview 1, 11/94). Nora's responses to the Attitude Towards Self as Science Teacher survey statements verify an increasing confidence in herself as a science teacher. Although she did not utilize cooperative group learning or the learning cycle, Nora practiced other teaching strategies (e.g., hands-on activities and eliciting prior knowledge) emphasized in her university education courses. When asked to describe her science classroom, when it was running as she wanted, Nora responded:

> Everyone is on task. I am strictly just a facilitator. Kids are all wanting to learn. They are using the computer. They are using the video machine. They are able to use books to find research in. They are really just kind of taking off on their own. They are . . . wanting to find things that they said they wanted to learn about. They are just excited about science as a whole (Interview 3, 4/95).

When asked if she had yet experienced that particular set of circumstances, Nora replied, "To some extent at some point," but her enthusiasm never faltered.

Summary. Nora verbalized and demonstrated her commitment to teaching science at the elementary level. She expressed confidence in her abilities to plan and prepare appropriate lessons for her students. She also took responsibility for identifying and overcoming any content or pedagogical deficiencies she exhibited. Perhaps with the support of her teaching colleagues, Nora will one day realize her wish for a science-centered elementary curriculum. She exhibited a firm grasp on science as inquiry and had tried to implement most of the pedagogical techniques she encountered at the university. Her plan to reconsider using the learning cycle was especially encouraging.

NonQUEST Teachers

Melanie

Melanie, with social studies as her area of concentration, was in a first-year teaching situation quite different from the other participants in the study. She was the only first grade teacher in an overcrowded Preschool-Grade 3, government-supported, day-care center/primary school in Chicago's inner-city. The enrollment in her classroom fluctuated frequently, but hovered around thirty children - not all of whom spoke English.

Melanie listed her youth, friendliness, and cheerfulness as her strengths as a teacher. All of these were important to her as she tried to overcome communication and economic barriers to teaching. She briefly described the situation, "A lot of these kids are on welfare. A lot of them don't get dinner at night, I know that for a fact. . . . They don't shower for days. . . . Lot of other problems that are more important than reading" (Interview 2, 2/95). She was also discouraged by the lack of support she received from parents and the other teachers at the school. Melanie freely admitted that the excellent working relationship she had developed with her part-time teaching assistant (an undergraduate education major at a local university) kept her focused on completing the full year of her first teaching assignment. She summarized her feelings as " . . . between the two of us, we want to do a good job . . . but it just exhausts me" (Interview 2, 2/95).

Science Content Knowledge. The results of the Science Content Test for Melanie were relatively low (see Table 2). She admitted, "My grades in science have never been good. . . . But I have always enjoyed it" (Interview 1, 11/94). However, on the three surveys, Melanie exhibited fairly neutral levels toward science and science teaching before and after her first year of teaching (see Table 2).

The interdisciplinary nature of science was interpreted by Melanie as integrating other curricular areas with science. She usually began with a trade book and developed "a thematic unit which covers everything" (Interview 1, 11/94). Emphasizing reading with the first graders, Melanie expressed surprise at discovering the relationship between the reading process skills and science:

> . . . we were doing classifying [and] seeing what comes next in sequencing things. . . . I never really mean to do it. It just kind of happens. So when I noticed it, I played off with it more (Interview 3, 4/95).

During the first interview, Melanie expressed some support for science as inquiry:

> I'd like for them to observe. . . . I would like them to make a hypothesis, like the potato has grown or the flower has stems because. To understand really what they are talking about. . . . be able to kind of get the grasp of things and enjoy it.

She commented that science is "probably the easiest thing for all my students to learn. . . . because it's hands-on. . . . If you're actually doing it and seeing it, then you learn it." However, the logs of science lessons revealed a distinct lack of hand-on experiences for the children.

It is interesting to note that all of the observed lessons provided a variety of appropriate hands-on activities for the first graders. Although Melanie had admitted to being only an average student in science content courses in high school and college, she was never observed expressing unacceptable science conceptions.

Pedagogical Knowledge. When asked about using the learning cycle, Melanie explained her science teaching strategy, "I probably do it opposite. We probably read about [the concept] and then we play with it so they know about it" (Interview 2, 2/95). This was an endorsement of a language-based curriculum, rather than a science-centered program. Melanie later explained, "I'm more concerned about reading and math than I am about science. . . . For first grade anyway, they have to know how to read to do science basically" (Interview 2, 2/95).

To this first-year teacher, social interaction among the children was important for learning in all subjects. Melanie said that she groups the students "almost always, unless they are doing their book work. But they can help each other. They work quietly then" (Interview 1, 11/94). However, she never assigned roles to the students as in formal cooperative group learning methods.

Melanie made little effort to elicit children's prior knowledge of science concepts. The observed lessons began with a few questions, but the discussions were limited to provide time for the activities. When asked about using problem solving with the first graders, Melanie replied, "I guess I give them some suggestions, but we don't really do that" (Interview 2, 2/95). Student choice was another area Melanie limited for the children:

> I think it's important to see what they like. But then, I think . . . they need direction. They can't just pick something up. They can have a couple or three choices and then they can choose on their own. But they need help getting it started (Interview 2. 2/95).

Pedagogical Content Knowledge. Melanie's attitude toward teaching science seemed based on her personal experience:

> I remember when I was younger, my [elementary science] teacher was boring. It was all from the book. That is probably one of the reasons why . . . I am not good at it. We didn't do anything fun [then]. We keep it fun [now] (Interview 1, 11/94).

Melanie's past experiences may also explain her disturbing response when asked to describe her science classroom when it's running the way she wants:

> We start off with packets [of worksheets], so it's pretty quiet. Then usually once a week or every two weeks, we'll do something [hands-on]. Then, it's usually pretty mellow-discussions, questions. They love it. They are just curious (Interview 3, 4/95).

During the final interview, Melanie expressed some positive changes in attitude toward her teaching assignment due to the development of her first graders:

> It's hard to believe it, but they are very much self-sufficient now from when they first started. . . . And before it was just like the most exhausting, . . . and now it's a pleasure because they are all reading. . . . I am much happier because I'm not as tired because they're not babies anymore (Interview 3, 4/95).

According to the monthly logs Melanie kept, she taught science three days per week until near the end of the school year. By March, science lessons were reduced to only Tuesdays and Thursdays at the end of the day. She admitted in the interviews that she usually alternated science and social studies lessons every two weeks. In addition to fewer opportunities for science, the logs showed Melanie's disheartening consistency in providing primarily demonstrations, readings, and discussions for the first graders, with few hands-on activities recorded.

Another comment Melanie made was in response to the question "What do you think is most important for students at this level to learn in science?" She replied, "I think they should think it's fun, because most people don't think it's fun. As a first grader, that's about all. . . . sometimes it's more important just to make them happy" (Interview 2, 2/95). Science can be fun, but it should include other objectives as well.

Summary. Melanie demonstrated her capabilities to teach science to her first graders. The lessons that she prepared for formal observations were well planned, featuring appropriate hands-on activities that the students found exciting. However, a true commitment to teaching good science lessons on a regular basis did not exist. As the logs and interviews revealed, science lessons in Melanie's class were intermittent, at best. She exhibited and admitted little value of the learning cycle, children's prior knowledge, and student choice in elementary science education.

Michael

Teaching second grade in a K-5 public elementary school in a mid-sized city in Northeastern Indiana was the first-year assignment for Michael, formerly a nonQUEST student with no area of concentration as an undergraduate. There were two other second grade classes in the building, but each was self contained. Michael's curricular responsibilities included reading, language arts, spelling, mathematics, social studies, health, and science. The 21 students also had classes in art, music, and physical education taught by other instructors. The students also spent time in the computer lab four days per week and one session in the media center (school library). Michael identified understanding as his strength as a teacher:

> I think I understand where a lot of these kids come from, some of the things they have to deal with. . . . I think by being young, I am able to understand some things that are going on, and the things that they see, and are exposed to (Interview 3, 3/95).

Science Content Knowledge. The interdisciplinary nature of science was not evident in Michael's science lessons. None of the observed science lessons included any bridges of the various science disciplines. In fact, this first-year teacher also interpreted the phrase to mean integrating science with other subject areas. When asked about using this approach with his second grade class, Michael stated that he seldom did, ". . . I don't have the time, or maybe I should say that I don't take the time to try to find all of these ways [to integrate the curriculum]" (Interview 3, 3/95). However, prior to each observed science lesson, Michael quieted the students returning from noon recess by reading aloud a trade book that related to the concepts presented in the science lesson.

Michael supported few components of science as inquiry in his science teaching, although he expressed these thoughts:

> To me science is all about why. . . . It answers so many questions for you - for them, for me. Just as to why things happen. . . . If that's this, then why? You get all kinds of lights going off in your head as to why things happen (Interview 1, 11/94).

He provided few, if any, opportunities for discovery or investigative hands-on activities. Michael, however, seemed to understand that there is no one scientific method. He remarked at one point that "Science has a procedure that you need to follow and that's fine, but I think you can vary from it" (Interview 3, 3/95).

Presenting unacceptable or incorrect science conceptions was never observed of Michael during his interactions with the children. His scores on the Science Content Test showed that he had improved his understanding of basic science concepts since early in his preservice program (see Table 2). However, Michael was aware of his limitations in this area and mentioned how he handles it:

> If there's something I want to do and I'm not real positive about it, . . . then I'll have to do a little research on it just so I'll kinda know what's going on. Sometimes they throw in one of those questions you don't know. You hate to get them but you do. You get them because you don't know everything (Interview 1, 11/94).

Pedagogical Knowledge. Overwhelming concerns with classroom management hindered Michael's science teaching, "I'd say that probably half of what I do, if not more is classroom management. Preparing them to learn, . . . not so much as teaching something. But preparing them, getting them ready to get into the mind set to be able to learn" (Interview 3, 3/95). He summarized his situation simply as a "lot of things depend on [the behavior of] the kids" (Interview 3, 3/95), including the science teaching strategies he employed. Pairing or grouping the children was not usually done because the children would agitate each other to the point where Michael would cancel the activity and/or science lesson.

After being reminded of the phases of the learning cycle, Michael baldly admitted, "No, I haven't done much with that' (Interview 2, 2/95).

There was little time allowed for exploration activities and even less time allotted for concept application. He stated that a science lesson

> . . . mostly starts out with a slight discussion. Then maybe some explanation to it. Then they get to work on it. There might be a wrap-up or discussion just to make sure that they had a clue as to what we spent the last 20 minutes talking about (Interview 3, 3/95).

When queried further, Michael said that he liked to begin science lessons by asking questions of the children to "see what they know about it and then go from there. . . . I don't just start lecturing to them. I try to see what's going on first." (Interview 2, 2/95). Eliciting prior knowledge was demonstrated in each of the three formal observations. However, it was also observed that Michael sometimes did not directly respond to or act on (i.e., change a planned lesson) students' comments.

Michael also used questions to get his students thinking for themselves.

> I try to give them a variety of questions . . . to get them to use life experiences or whatever so they can figure things out for themselves, on their own. That always helps - helps them understand and pull things together (Interview 1, 11/94).

He also claimed to do a lot of problem-solving in a lot of subjects, not only science, "just to get them to think and try to figure out different ways to work out things" (Interview 2, 2/95).

<u>Pedagogical Content Knowledge.</u> At the beginning of the school year, Michael had dedicated 30-minute sessions on two Friday afternoons each month for science. At the start of the spring semester, he added an occasional Tuesday afternoon science class. By the end of the year, science lessons were planned for every Tuesday and Friday afternoon. As recorded in the monthly logs, the lessons advanced from reading and discussion sessions to hands-on experiences that were sometimes integrated with other subject areas. This increase in time for science may be explained by the positive change in Michael as measured by the Attitude Toward Self as Science Teacher survey (see Table 2). His neutral feelings during his preservice education about teaching science veered to the positive during his first year of teaching.

In response to the question "How do you decide what to teach and what not to teach?" Michael said, "That's what I'm learning now. I'm learning that all the time. Sometimes I use my judgement, just to say, 'That's no big deal. They will pick that up later'" (Interview 1, 11/94).

Michael described the most effective way to teach science as follows:

> . . . with visuals, open discussions, and somewhere in there to try to get them some kind of manipulative - some kind of hands-on something for the children to get their hands on so that they learn through touch. They just can't pick everything up by listening. . . . I think it helps for a lot of grades - even up through college. When you're able to talk about something and be able to pick that something up and look at it, flip it over and look at it another way (Interview 2, 2/95).

Michael would appear to emphasize engaging the students in hands-on science activities. However, that was not the practice in his classroom. Hands-on activities were also absent from Michael's description of a well-run science class, "You have people working together. You have talk. You have discussion about the task at hand. During discussion you get questions pertinent to the topic" (Interview 3, 3/95).

Michael readily confessed, "I'm pretty dependent upon the materials I'm given here" (Interview 1, 11/94). He repeated this sentiment at the end of the school year, also. Michael expressed some concern about feeling textbook bound. That was a major reason why he liked having the science kits that the school district had begun using in the elementary schools. He had hoped to use the software programs that came with the new science kits, but they were incompatible with the computers available to him and his students. Therefore, technology used in science was usually watching videotapes.

Michael acknowledged his reluctance to teach a topic that did not appeal to him. He further admitted that "I don't know what it is that [the second graders] need to know [in science]" (Interview 3, 3/95). However, choosing a topic to teach led Michael to spending a lot of time in science and in other curricular areas

> taking knowledge or information and breaking it down into something that [the students] can grasp. Maybe like experience, maybe just into their own terms - an explanation or something. Just making that into language they can understand and words they normally use and do understand (Interview 3, 3/95).

Summary. Michael's willingness to increase the time allotted to science for his second graders was a positive move for him. However, his lack of practicing pedagogically sound techniques and his deficiencies in knowing what to teach are distinct disadvantages for this beginning teacher.

Conclusions

What is the state of the first-year teachers' science content knowledge, pedagogical knowledge, and pedagogical content knowledge?

In regards to the examined aspects of science content knowledge, the four first-year teachers exhibited some differences and some similarities. All four of the novice teachers interpreted the interdisciplinary nature of science as the integration of science with other subject areas rather than across the science disciplines. Each of the teachers supported the notion of science as inquiry during interviews and surveys, however, Nora was the only one who showed any true evidence of its practice in her classroom. Although none of them was observed teaching scientific inaccuracies or experiencing other difficulties with science content, only Patty felt extremely confident of her understanding of concepts she would be expected to teach.

Some of the most surprising results were found in the area of pedagogical knowledge. None of the teachers utilized the learning cycle approach to teaching science, although all of them had practiced this particular teaching strategy with children in the field experience coordinated with the elementary science methods course. Cooperative group learning, problem solving, and student choice in learning were emphasized in several of these beginning teachers' methods courses (in addition to the science methods course) yet none of these pedagogical techniques were regularly included in science lessons. Patty, Nora, and Michael habitually elicited the prior conceptions held by their students. However, Michael rarely incorporated the children's ideas into the lessons.

The degree of pedagogical content knowledge exhibited by the novice teachers seemed to be decided by the amount of control over their students that the teachers needed. Although they all promoted hands-on learning in science, only Nora appeared comfortable with preparing and using manipulatives in discovery learning situations. Classroom management concerns tended to determine what would be taught in the other classrooms.

What differences in the three types of knowledge exist between first-year teachers with the science area of concentration and first-year teachers with other areas of concentration?

The first-year teachers' overall science content knowledge does appear to increase, as expected, with more science content courses completed. Although there was some variety between individuals, the beginning teachers demonstrated similar pedagogical knowledge. Perhaps this finding can be explained by the repeated consideration of these same aspects of pedagogy in other teacher education classes, common to all of these novice educators during their undergraduate coursework. While none of the four first-year teachers demonstrated a truly adequate pedagogical content knowledge, the two QUEST teachers consistently expressed and displayed more commitment to providing learning opportunities in science to their elementary students.

What changes in science content knowledge, pedagogical knowledge, and pedagogical content knowledge are exhibited by the first-year teachers as they have progressed from the university setting to the elementary classroom?

With regard to the third research question, it became apparent that written responses to questionnaires or paper/pencil instruments alone would not have provided sufficient information about the inservice teachers. Table 2 reveals differences over time for the quantitative instruments, however, "Observation of actual practice reveals how the different things that a teacher knows and believes come together in making decisions and pedagogical moves" (Kennedy, Ball, & McDiarmid, 1993, p. 99). There were many discrepancies between the teachers' responses on surveys and in interviews to what they actually did in the classroom. In the matter of how best to teach science to children, all of the teachers espoused *hands-on learning*, however, their monthly logs revealed a preponderance of readings and discussions. The teachers did not translate their stated beliefs into classroom practice.

Implications

From the case study of Marie, a science enthusiast student teacher, Abell and Roth (1992) assert that "Limited content and pedagogical content knowledge may be the biggest constraint for novice teachers in elementary science, especially those who do not begin as science enthusiasts. Unfortunately it is not a constraint that is ameliorated by experience or increased confidence alone" (p. 592). The same inference cannot be made from this investigation of first-year elementary teachers. Each of these novices repeatedly attributed their discrepant actions primarily to the constraints of time, but also classroom management concerns and problems within the school environment. In their case study of a new chemistry teacher, Schulke, Yocum, and Gallagher (1991) asserted that "time management became her greatest concern" (p. 7). Pigge (1981) found that 60% of the first-year teachers he surveyed said that discipline and classroom management was the area in which they wished they had greater proficiency.

In her study of how teachers become professionals, Cunliffe (1994) emphasizes the importance of the beginning teacher "demonstrating the awareness of and concern for student learning, and the ability to plan and use strategies to enhance this" (p. 17). The novice teacher must be functioning beyond what Spector (1989) would call *survival* in the classroom. Herndon and Fauske (1994) succinctly state that "encouraging best practice means encouraging reflection about teaching" (p. 3). Apparently, the teachers in this study haven't found the time to spend in reflection; they're simply trying to survive from one day to the next.

Williams, Eiserman, and Lynch (1985) concluded that for one of the first-year teachers in their study, "most problems resulted from discrepancies between reality and her expectations of the students and herself" (p. 12). No matter how many times experienced educators and/or methods instructors try to illuminate for the preservice teachers the challenges of the classroom, novice teachers cannot truly understand those responsibilities until they face the reality of the inservice classroom.

The teachers in this study expressed confidence that, over time, they would develop the content knowledge and pedagogical skills enabling them to teach science to children more effectively. Carlsen (1987) pointed out that "new teachers often report that they don't really understand a topic until they've taught it a few times. It is important to keep in mind that subject-matter knowledge continues to change after teacher education and the formal study of science in college end" (p.18).

The *National Science Education Standards* (National Research Council, 1996) call for changes at the university level, declaring that "professors need to model exemplary science pedagogy and science curriculum practices. Teachers need to be taught science in college in the same way they themselves will teach science in school. Changing the pedagogical practices of higher education is a necessary condition for changing pedagogical practices in schools" (p.238). Modifications are needed in the science content courses and the science methods courses. Chaney (1994) investigated the relationship between teachers' academic reparation, their subsequent teaching methods, and student outcomes on proficiency exams. He concluded that although the teachers' number of courses in science education made no difference, the number of science courses taken by the teachers did influence the students' achievement. The QUEST Project has implemented some changes, in accordance with the *Standards*, in science content courses at Indiana University. Although success is obviously limited at this time, the results of this study provide sufficient impetus to continue with the new teacher education program, and to continually modify it to include more student involvement and reflective thinking across all courses. Success will be achieved only when support for changes in science education exists at all levels.

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Table 1

Data Collection Timeline

Data Source	Scientific Inquiry Course[a]	Elementary Science Methods Course[a]	Capstone Course[b]	First-Year of Teaching[c]
Science Log				beginning, middle, end
Observation				beginning, middle, end
Interview				beginning, middle, end
Lesson Plans				middle
Videotaped Teaching and Self-assessment				middle
Capstone Science Survey			beginning[d] and end	end
Attitude Toward Self as Science Teacher	beginning	beginning and end		end
Science Content Test	beginning	middle		end
Teaching Survey		beginning and end		end

Note. [a] Data were collected from all elementary education majors in this course.
[b] Data were collected from the QUEST students in the course and a comparison group of students with other areas of concentration.
[c] Data were collected from the nine participants in this study only.
[d] Data were collected from the students in the course only.

Table 2 Averaged Individual Results on Successive Administrations[a] of the Quantitative Instruments

Teacher	Capstone Science Survey (+2 → -2 scale[b]) 1	2	3	Attitude Towards Self as Science Teacher (1 → 5 scale[c]) 1	2	3	Science Content Test (%) 1	2	3	Teaching Survey (1 → 5 scale[d]) 1	2	3
QUEST												
Nora	+0.46	+1.2	+0.71	1.6	1.1	1.0	31	62	78	2.2	2.6	2.5
Patty	+0.54	+0.46	+0.46	1.6	1.0	1.8	72	85	90	2.6	2.3	2.0
NonQUEST												
Melanie		+0.17	+0.25	2.6	---	2.4	45	--	68	---	---	2.4
Michael		+0.62	+0.38	3.0	2.9	1.8	72	68	90	2.4	2.6	2.2

Note. [a] See Table 1 for instrument administration timeline. [b] Ratings are based on the following scale: +2 = evidence demonstrating full understanding/valuation/application, +1 = evidence suggesting partial understanding/valuation/application, 0 = no evidence or contradictory responses, -1 = evidence suggesting some misunderstanding/valuation/application. -2 = evidence demonstrating definite misunderstanding/valuation/application. [c] On this 1 → 5 scale, 1 represents a positive attitude and 5 represents a negative attitude. [d] On this 1 → 5 scale, 1 represents a constructivist philosophy and 5 represents a more traditional philosophy.