Connecting Science and Mathematics Instruction: Pedagogical Context Knowledge for Teachers

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Although the reform literature in mathematics and science is replete with calls for the integration of math and science, there remain precious few empirical studies examining the prerequisite skills, beliefs, knowledge bases, and experiences necessary for teachers to implement integrated instruction. The initial intent of this study was to examine the content knowledge, pedagogical content knowledge, attitudes, and beliefs (with respect to the integration of mathematics and science) that prospective secondary mathematics and science teachers bring to their respective preparation programs. This study then explored a collaborative model intended to create meaningful educational opportunities within the context of teacher preparation programs to foster preservice teachers' desire and ability to pursue connected teaching in the classroom. Presented in the article are findings related to the initial beliefs and experiences prospective teachers bring to the preparation process, the results of their collaborative work together in the creation of interdisciplinary units connecting mathematics and science topics, and their ongoing efforts to work together once engaged in schools for their student teaching internships. Moreover, this article proposes subtle shifts in both the conceptualization of, and language used to describe, the integration of mathematics and science. Building on sociocultural theories, this article proposes the use of connections *and* pedagogical context knowledge *as levers to promote integrated mathematics and science instruction.*

Nearly 100 years ago, E.H. Moore (1902) delivered a presidential address to the American Mathematical Society in which he stated,

> Engineers tell us that in the schools algebra is taught in one water-tight component, geometry in another, and physics in another, and that the student learns to appreciate (if ever) only very late the absolutely close connection between these different subjects, and then, if he credits the fraternity of teachers with knowing the closeness of this relation, he blames them most heartily for their unaccountably stupid way of teaching him.

Moore went on to advocate reforms in school mathematics and science instruction that would prompt a more coherent organization of the two subjects, including overlaps between them. Now a century later, one might pause to consider the progress teacher educators have made in helping both teachers and students not only see the important connections between the disciplines, but also understand how one discipline can support learning of the other.

It is true that the recent reform movements in school science and mathematics include the notion that the two subjects be integrated as a means of strengthening students' understanding of and appreciation for the many connections and applications that link science and mathematics (American Association for the Advancement of Science, 1989; Good, 1991; National Council of Teachers of Mathematics, 1989; National Research Council, 1996; Roth & Bowen, 1994). In fact, the natural overlaps in school science and mathematics have led some educators to suggest that the two subjects be integrated to the extent "that it becomes indistinguishable as to whether it is mathematics or science" (Berlin & White, 1992, p. 341).

Yet, is the educational community still running the risk of being in the words of Moore, "unaccountably stupid" in the ways in which teachers are prepared to integrate mathematics and science? Certainly, fostering such strong interdisciplinary connections is a challenging task for teachers and teacher educators, made all the more difficult given the paucity of research that explores what it means to integrate science and mathematics teaching (Berlin, 1991; Berlin & White, 1995).

The first purpose of this article is to present an innovative model of secondary preservice teacher education that was designed to provide rich and meaningful experiences for beginning teachers to begin seeing and seeking connections between science and mathematics. The second purpose of this article is to share research examining the perspectives of preservice teachers on connecting mathematics and science within the context of this innovative preparation program and into their subsequent student teaching experience. By examining the perspectives, lesson planning, and teaching of the preservice teachers who participated in the program, this article provides empirical evidence that points to the promise and potential of promoting pedagogical context knowledge (Barnett & Hodson, 2001) as a mechanism through which science and mathematics may be more closely explored and understood by both teachers and, ultimately, learners in school classrooms.

Conceptual Framework for Connecting Science and Mathematics

The following conceptual framework for connecting science and mathematics teaching describes the ways in which contemporary theories of situated cognition in science and mathematics provided underpinnings for the conceptual design, implementation, and evaluation of the program under examination. In particular, the notion of situativity is explored as it applies to *teacher* learning, as well as the role pedagogical context knowledge plays in fostering integrated instruction in science and mathematics.

Learning in Context: Situativity

Constructivist theories guiding reforms in science and mathematics education suggest a major shift from learning science and mathematics as an accumulation of rote facts and procedures to learning science and mathematics in authentic contexts – as socially negotiated constructions and explanations used to make sense of the world (Cobb, 2000; Cobb & Bowers, 1999; Greeno, Collins, & Resnick, 1996; Putnam & Borko, 2000; Roth & Bowen, 1994; Roth & McGinn, 1998). Much of the debate about school science and mathematics in recent years, therefore, revolves around the differences between traditional classroom practice and the ways in which science and mathematics are used in authentic settings (Brown, Collins, & Duguid, 1989; Roth & Bowen, 1994; Roth & McGinn, 1998). Emphasizing the importance of situated uses of mathematics in everyday life (Lave, 1988), Lave's and Wenger's (1991) notion of situated learning has become a guiding paradigm for thinking about the authenticity of experience as a catalyst for growth and learning.

Recent studies have begun to extend the notion of situativity to the teaching and learning of science and mathematics (e.g., Cobb, Boufi, McClain, & Whitenack, 1997; McClain & Cobb, 2001; Putnam & Borko, 2000; Roth & Bowen, 1994; Yackel & Cobb, 1996). It has been recognized that the knowledge and skills that *teachers* acquire are fundamentally linked to the contexts within which those attributes are introduced and developed (Barnett & Hodson, 2001; Greeno, Collins, & Resnick, 1996). Furthermore, as Shulman (1986) has argued convincingly, these contextually developed knowledge structures are centrally connected to the ways teachers develop and practice their craft. It follows, therefore, that if science and mathematics teachers are expected to develop expertise in fostering integrated learning opportunities for their students, then a significant part of their preparation experiences should be contextually based. As Putnam and Borko (2000) have suggested, "How a person learns a particular set of knowledge and skills, and the situation in which a person learns, become a fundamental part of what is learned" (p. 4). A situative lens for teacher development, therefore, focuses on "interactive systems that include individuals as participants, interacting with each other as well as materials and representational systems (Greeno, 1997; Cobb & Bowers, 1999)" (in Putnam & Borko, 2000, p. 4).

Examples of Integration From a Situative Perspective

Responding to the call for research on connecting science and mathematics teaching and learning (Good, 1991), Roth and Bowen (1994) conducted an empirically based research study on the situated and authentic practice of eighth-grade physical science students. Drawing on social studies of knowledge (e.g., Latour, 1987), students worked collaboratively to frame problems themselves by generating "their own questions and problems, design[ing] solution strategies, and share[ing] their findings in a peer culture of learning" (Roth & Bowen, 1994, p. 294). Similar to the way scientists "mathematize" in their practices – the process of bringing mathematical order to natural phenomena – students in Latour's study engaged in developing representations or "inscriptions" of physical phenomena and relationships. Like scientific research, inscriptions take the form of graphs, charts, and equations that are interpreted as authentic, socially constructed, and negotiated "conscription" devices that enlist the participation and understanding of groups of people.

Moreover, in this study, negotiated inscriptions represented appropriate uses of mathematical principles and concepts in the context of using science.

In a later study, Roth and McGuin (1998) advocated the importance of science and technology studies for providing a context for learning science and mathematics. In their study, students participated in a 10-week ecology curriculum in which they researched a $40m^2$ square plot, or *ecozone*, on their school grounds. The researchers analyzed the student-generated inscriptions that illustrated the relationships between biotic and abiotic variables on a graph. Similar to scientists, Roth and McGuin contended students were engaged in the social practice of negotiating the science and mathematical interpretations of their data.

Integration and Context Knowledge

One of the primary purposes of this article is to generate ideas on what is necessary for teachers to integrate mathematics and science instruction effectively. The previously elaborated examples of integration naturally lead to another question: What kinds of knowledge structures are necessary for this kind of teaching?

The work of Barnett and Hodson (2001) has been instrumental in guiding our thinking about the research presented in this article. They articulated a theoretical framework that promoted the study of teachers' pedagogical context knowledge as a means for understanding what science teachers know and how they use that knowledge for teaching. This framework included four overlapping dimensions that provide a context for teachers' development: (a) pedagogical content knowledge, (b) professional knowledge, (c) classroom knowledge, and (d) academic and research knowledge. Two of these dimensions – pedagogical content knowledge and academic and research knowledge – are common elements of frameworks for teacher development. Specifically, pedagogical content knowledge (Shulman, 1986) includes "such things as knowing how to set teaching goals, organize a sequence of lessons into a coherent course, conduct lessons, introduce particular topics, and allocate time for satisfactory treatment of all significant concepts" (Barnett & Hodson, 2001, p. 438). Academic and research knowledge for teachers refers to content knowledge in the subject, including the nature of science.

The other two dimensions – professional knowledge and classroom knowledge – are instrumental concepts in more recent and emerging frameworks that embrace a situative lens for teacher development. Professional knowledge refers to "teacher lore" or knowledge about schools and curriculum passed on from experienced practitioners to young practitioners. The professional knowledge of teachers, field tested in the classroom, often eschews the academic knowledge of educational research. Classroom knowledge is the situational "craft knowledge" teachers have of their own classroom and students. Thus, pedagogical *context knowledge* embraces situated science teaching and learning in authentic contexts.

For the research elaborated in this article, a particularly compelling question about this framework – these four elements of the knowledge landscape – is when and under what conditions teachers develop this kind of context knowledge for teaching. Barnett and Hodson (2001) suggested that "there are three kinds of 'places' where knowledge is acquired, constructed, rationalized, and deployed: Private, semiprivate, and public" (p. 436). As they described, the teacher's personal reflections and cognitive activity is, of course, private and safe. Once teachers begin sharing the contents of their "private" knowledge, however, they enter into a zone where

> collective theories and values are constructed and where teacher lore is formulated. It is here that teachers' networks sometimes flourish and action research occurs.... Moving comfortably between and among these places requires an ability to switch quickly and effectively between different elements of pedagogical context knowledge: Academic and research knowledge, pedagogical content knowledge, professional knowledge, and classroom knowledge. (p. 437)

For the purposes of this research, we were most interested in the ways in which the preservice teachers in our program could be encouraged to enter the "semiprivate" spaces as a way to begin to develop knowledge and know-how for integrated instruction.

Toward a New Conceptual Model for Connected Science and Mathematics Teaching

The following framework is based on the previous synthesis of theories about teacher learning. Specifically, by definition, the integration of science and mathematics is necessarily situative. That is, in terms of student's construction of knowledge, in terms of curricular innovation, and in terms of teachers' pedagogical practices, fostering understanding of the relationships and connections between mathematics and science is contextually based. Hence, grounded on these assumptions, the following two conceptual shifts are promoted as potential turning points for integrated science and mathematics teaching and learning.

From Integration to Connections. First, the language used to discuss the relationship between science and mathematics must be carefully selected in order to promote different perceptions of and practices for science and mathematics instruction. There has been much debate in the research literature about the definitions of terms such as *interdisciplinary* and *integrated*, and the implications of those definitions for practice (Berlin, 1991; Berlin & White, 1995). To summarize briefly, definitions of interdisciplinary teaching include the assumption that the integrity of disciplinary boundaries will be preserved through exploration of common contexts that promote learning of both science and mathematics. Such a view predicates that teachers have both the content knowledge and pedagogical content knowledge to teach two disciplines successfully, science and mathematics.

This expectation, however, is often unrealistic, considering that beginning teachers are usually still developing competence in one field. Similarly, common definitions of "integrated" teaching imply that science and mathematics can be blended seamlessly so that it is difficult to tell where the mathematics stops and the science begins. This view of integration certainly has its own demands and challenges, as well.

In what may be a more realistic and hopeful approach, therefore, we advocate the use of terminology that includes the notion of *connections* between science and mathematics – connections that are situated authentically in the respective practices of each field and in the common experiences of learners. Although teachers may not have enough knowledge to "integrate" instruction, or are not able (i.e., lack of time, school structure, etc.) to work collaboratively toward "interdisciplinary" teaching, many teachers are able to recognize and build upon various connections between mathematics and science that they see as intuitive and relevant. Rather than resting primarily within the constructs of each discipline, these mathematics and science connections tend to emerge from the prerequisite knowledge bases and experiences of teachers.

Pedagogical context knowledge. The conceptual shift toward *connected* mathematics and science teaching provides a new way to interpret the knowledge bases that teachers bring to the classroom. Specifically, though the idea of pedagogical content knowledge is fundamental to good instruction of any kind, one essential construct for connected mathematics and science instruction is the idea of pedagogical context knowledge (Barnett & Hodson, 2001). That is, given the situativity of connected science and mathematics curriculum and learning, it is important that teachers understand the contexts that hold potentially significant mathematics and science connections. That is, if one ascribes to situative perspectives on learning – that students and teachers construct meaningful knowledge of science and mathematics through interaction – then rich contexts become essential in order to promote deep thinking and learning and recognition of the symbiotic relationship between mathematics and science. Hence, pedagogical context knowledge must be a starting point for teachers' growth and development with respect to promoting connected instruction.

Issues of Content Knowledge and Pedagogical Content Knowledge

To teach in a way that allows students to construct meaningful knowledge structures, teachers must possess richly connected understandings and content knowledge in their subject matter (Ball, 1990a). Yet, as Shulman (1986) suggested, content knowledge alone is inadequate unless the novice teacher has also acquired pedagogical content knowledge – the ways of "representing and formulating the subject that make it comprehensible to others" (p. 9).

Despite the many calls for rich content and pedagogical content knowledge for teachers, there is a considerable body of research suggesting that novice teachers often do not possess the content and pedagogical knowledge to teach for understanding in their respective disciplines (e.g., Adams & Krockover, 1997; Ball & McDiarmid, 1990; Brown & Borko, 1992). Research findings confirm that knowledge gaps exist in mathematics (Ball, 1990a, b; Brown, Cooney, & Jones, 1990; Frykholm, 1996, 1998) as well as in science (Lederman, Gess-Newsome, & Latz, 1994).

These deficits in content and pedagogical content knowledge are significant, considering the ways in which prospective teachers tend to rely heavily on previous knowledge and experiences when making teaching decisions (Brown & Borko, 1992; Frykholm, 1996; Hammrich, 1997; Lumpe, Haney, & Czerniak, 2000). Important for this research is how issues of content and pedagogical knowledge become even more salient when beginning teachers are asked to connect and contextualize two bodies of knowledge – science and mathematics.

Both the preparation program and research study described in this article rest on the notion that *any* effort to connect science and mathematics with meaning must be situated in authentic contexts. This premise holds for both the *content* of the learning itself, as well as the *process* in which teachers engage that helps them develop the craft and content knowledge necessary for guiding students through authentic, rich, integrated experiences in science and mathematics.

Research Context

Research Purpose and Guiding Questions

Theories about situated learning and contextualized science and mathematics teaching provide a framework with which to think about exploring teachers' knowledge for teaching. We viewed the preservice teacher education process as an opportunity for prospective mathematics and science teachers to be both learners of subject matter content and learners of contexts for teaching these subjects. Specifically, this study was designed in an effort to examine three particular research questions:

1. What are prospective science and mathematics teachers' understandings and experiences as related to connecting science and mathematics teaching and learning?

2. What are prospective science and mathematics teachers' perceptions of their content and pedagogical content knowledge with respect to connecting science and mathematics instruction?

3. How does a contextually based approach to connecting science and mathematics teaching and learning in the preparation process influence the thinking and practices of the participants during their student teaching experience?

Methodology

Research Study

This study was framed within the contexts of two secondary preservice teacher preparation strands (i.e., one in mathematics and one in science) over a 2-year time period. The process described in this section was completed in 2 successive years, with two different cohorts of preservice teachers. This study took place during the second course of a two-semester methodology sequence that immediately preceded the student teaching internship. Although the participants were not formally required to participate in the study, their engagement in this work was part of the context of the course.

Thirty-four prospective teachers (12 science, 22 math) participated in the study in the first year, and 31 preservice teachers (11 science, 20 math) participated in the second year. Of the 65 participants, 32 were graduate students, and 33 were undergraduate students enrolled in a licensure program at a large state university. With only a few exceptions, the participants were "traditional" students in the sense that they had not returned to the university classroom for teaching credentials after a previous career. Although there was no control for differences in groups from year 1 to year 2, no significant differences or trends in the data were found to suggest variations in the existing knowledge structures or interactional patterns of the respective groups.

In both years, an identical structure was used to facilitate interactions between prospective mathematics and science teachers that allowed the researchers to explore their students' beliefs about connected mathematics and science teaching, their content and pedagogical content knowledge as related to connected mathematics and science teaching and their ability to collaborate to create a context for learning science and mathematics through curriculum projects and activities. Five groups were created around content areas, including biology, chemistry, earth science, physical science, and physics. The groups typically had a mixture of five to seven prospective teachers in mathematics and science. As often as possible, groups were organized such that the prospective teachers would be able to work with peers who were going to be student teaching in the same schools in the following semester. In addition to facilitating the group interactions, the two instructors for the respective courses completed all phases of the data collection and analysis.

To generate data about the existing knowledge of the participants, each group was instructed to develop a curriculum project that would connect science and mathematics concepts. The participants were encouraged to design units (or, for some groups, lesson plans) that they would be able to implement during their teaching internships, if possible. Thus, the curriculum projects included statements of purpose, content focus, learning goals, and descriptions of learning activities and outcomes as they pertained to connecting science and mathematics. As such, these connections involved applications to scientific research or examples from everyday experience.

Data Sources

To address the research questions framing this study, data were collected and triangulated in various ways. Contributing to the data record were audiotaped large-group discussions, audiotaped small group collaborations, observation notes taken by researchers during group interactions, written responses to various questions posed by instructors at various points of the semester, journal entries recorded by participants during the teaching internship, audiotaped group presentations, curriculum units created by each group, lesson plans, and classroom observations completed during the student teaching experience.

Data Analysis

As noted, the two instructors of the courses also conducted the collection and analysis of data. All analysis of data was done in parallel, with multiple opportunities for the researchers to co-analyze data, discuss emerging findings, and develop reliable coding strategies. The data analysis was influenced by several models of qualitative research (Erickson, 1986; Spradley, 1979a,b; Strauss, 1987; Wolcott, 1993). Although these researchers do not share identical views on the processes of qualitative research, each provided advice that was helpful in the systematic analysis of the data in this study. For example, Strauss (1987) recommended an iterative "coding" process, whereby a systematic and ongoing fracturing of the data leads to the identification of core themes and categories emerging from the data record. Once initial codes have been established, Spradley (1979b) emphasized the need to organize codes based on their relationships to one another. These "domain analyses" are helpful in generating empirical assertions based on confirming (or disconfirming) evidence (Erickson, 1986). Specifically, as transcriptions and written responses were read carefully, relevant data excerpts were categorized in reference to the questions guiding this investigation.

As a brief example, responses gathered from writing exercises early in the semester revealed similarities in the perceptions of the mathematics preservice teachers with respect to their science content knowledge. As these mathematics majors repeatedly commented that they felt insecure in their knowledge of science content, it became clear that this issue – knowledge across content areas – would inevitably play a role in the collaborative projects developed by each group. In the ongoing analysis of subsequent data sources, therefore, emerging evidence of "content knowledge" within the context of science and mathematics and its effect on the collaborative process was aggregated and carefully examined.

Findings and Discussion

The findings of this study are organized under three headings. First, the participants' conceptions and experiences related to connected mathematics and science are presented. Second, the group collaborations are used as a context to explore the participants' engagements with one other, the knowledge bases from which their collective work emerged, and the ways in which their shared understandings contributed to the curriculum projects. Third, evidence gathered during the student teaching internships regarding the participants' dispositions (and steps taken) toward connecting science and mathematics in the classroom is presented.

Perceptions About Connecting Science and Mathematics Teaching and Learning

The importance of connections. Almost without exception, the participants conveyed strong convictions about the importance of connecting mathematics and science instruction. Representative of many similar statements in which teachers used the term "integration" interchangeably with "connections," one mathematics student teacher suggested that it was "important to integrate mathematics and science because they can further understanding of one another" (John, Cohort 1; written reflection). Others stated their convictions more strongly, as in the case of one individual in science who noted that he was "not willing to teach either mathematics or science without integrating them with the rest of the curriculum" (Kevin, Cohort 1; written reflection). In no instance did a participant suggest that connecting mathematics and science was something that should not, or could not, be pursued.

The participants also indicated repeatedly that connecting the two subjects was not only important, but also possible. The very idea of linking mathematics and science seemed intuitively obvious to many participants, as represented in the following remarks of a prospective mathematics teacher: "The connections between mathematics and science exist at almost any level or topic that you could choose. Asking if mathematics is necessary to teach the sciences or vice versa is like asking if scissors are necessary for a haircut" (Michael, Cohort 2; written reflection). Similarly, Sarah (Cohort 2), a future science teacher, shared her contention in a large group discussion that "it is almost impossible not to combine mathematics and science, at least from the perspective of a scientist....After all, mathematics is just as integral and a part of chemistry and biology as the scientific theories are themselves."

Many of the prospective teachers commented about the natural overlaps in mathematics, science, and real world events. As Angie (Cohort 2), a prospective mathematics teacher, summarized in a written reflection, "Integrating mathematics and science shows students how applicable mathematics is in the natural world. They are using mathematics to make sense of the world around them."

Apprehensions and concerns. Despite these references to the many natural overlaps in science and mathematics, a number of these prospective teachers commented about how seldom they had seen these connections emphasized in their classroom experiences. As Brian (Cohort 2) recalled during a classroom discussion, "My personal experience with integrating math and science has been non-existent." Another participant shared that integrating mathematics and science "intrigues me a great deal. But my exposure to it in high school was horrible. My teachers were bad, as was the design of the class content" (Michelle, Cohort 1, written reflection). One of the mathematics preservice teachers similarly shared his perception of how fragmented the school curriculum was:

> I feel like I would need to do a lot of research and preparing in order to connect mathematics and science in a meaningful way. I was not exposed to interdisciplinary settings during my school years. The mathematics courses were specialized topics, and so were the [science] courses. Obviously, some algebra was used in chemistry and other mathematics was used in physics, but connections were never emphasized (Chris, Cohort 2, written reflection).

Perhaps due, in part, to this general lack of exposure to settings in which mathematics and science were connected, the participants expressed some hesitation as they approached the collaborative experience. One prospective mathematics teacher reported that she could not come up with many specific examples of mathematics and science overlaps that would be appropriate for the secondary mathematics classroom and, therefore, "was kind of reluctant about meeting with the science people" (Michelle, Cohort 1; classroom discussion).

In general, the participants seemed most concerned about their lack of content knowledge in whichever field was not their primary content area – either mathematics or science. Several of the prospective science teachers made comments suggesting that they wished they had had a better experience in mathematics courses. As one noted,

> I never had a good mathematics teacher – they seemed to have only one way to explain how to do a problem, and if that didn't make sense, you were out of luck. I am fine with algebra, but uncomfortable with geometry and hopeless with calculus (Kevin, Cohort Two; written reflection).

The notion of adequate content knowledge in the sciences was equally problematic for the prospective mathematics teachers, most of whom had spent little time studying any particular branch of science. One prospective mathematics teacher expressed her concerns by noting, "I certainly don't think I lack in the mathematics background, but I feel shaky about having the science background needed to truly connect the two" (Danielle, Cohort 1; classroom discussion). Similarly, another mathematics major suggested the following:

> I am not very prepared to connect the two [mathematics and science] because I do not have a good grasp on science. I personally had a hard time in all science classes and don't particularly enjoy the subject. But I feel it is important to connect the two, and I am willing to learn how (Christy, Cohort 2; written reflection).

This quote represented the sentiments of many of the prospective mathematics teachers. Although they admitted that they were somewhat shaky in terms of their science content knowledge, they were aware of the importance of connecting the two subjects in their teaching and were eager to learn more about how to do so.

The Collaborative Projects: Situative Contexts for Learning

Connecting knowledge. Despite the initial reservations of the prospective teachers concerning the integration of subjects, a different picture emerged as they began to collaborate on their curricular units that were designed to provide an authentic context for teaching science and mathematics. The silence marking the initial moments of each group meeting was sharply contrasted with the animated interaction and conversation once the groups began sharing ideas and possibilities for their unit creations.

Due to the implied understanding that the project from each group should fall within a particular broad science topic area – biology, for example – the prospective science teachers tended to take the initial lead in suggesting broad topic ideas. As they explained the primary content of the topic, the mathematics majors tended to interject ideas about how mathematical concepts might be appropriately connected. Raising the question of the degree to which each discipline provides a context for pursuit of the other, one participant shared in the midst of his small group discussion, "It seems easier to throw out science ideas first and then see what mathematics is in them, rather than to do it the other way around – math first" (Kevin, Cohort 2; small group discussion). Following this process, each of the five groups quickly generated a wealth of possible ideas to pursue and easily developed elaborate unit plans, complete with sketches of activities, labs, technology applications, and authentic assessments in which the mathematics and science connections were explicitly conveyed.

As they worked together on the curriculum projects, there was a notable shared sense of purpose and spirit of cooperation. As one prospective mathematics teacher noted in a journal entry at the conclusion of the first interactive group session,

> I was hesitant about doing this, but since I did it, it was very helpful. For one thing, it helped me realize just indeed how many ideas and applications I could think of...It was through the group's conversations that my thoughts were prompted (Sarah, Cohort 1; Journal reflection).

A number Sarah's peers shared similar sentiments – that they were surprised not only at the collective wealth of knowledge in the group, but also at the depth of their own knowledge as it was uncovered through conversations with each other.

Connected unit plans. In developing a unit plan around a particular science topic with applications from scientific research or everyday experience, the participants examined the inherent mathematical and scientific principles and developed rough sketches of a series of lessons that would build upon each other throughout the unit. The culmination of their work was a presentation made to the rest of their peers. As they presented their ideas to the larger group, each team highlighted the connections between science and mathematics that were represented in the unit plans.

Across the 2 years, numerous topics became the foci of the units of instruction developed through the collaborations. Although space does not allow for an elaborate analysis of the content of each of the units developed, references occur in the following data excerpts to a number of the units that were developed, taught, and observed, including tree growth, airplane flight, various physics phenomena, endangered species such as manatees, and invertebrates and vertebrates.

To indicate the depth of integration present in many of these units, one brief example is included here. During the first year, the biology/mathematics group created a unit that explored tree growth. Among other ideas, they planned activities that would examine (a) tree age based on a cross section of the trunk; (b) ring width as a function of the amount of rainfall in a given year; (c) tree populations and density with respect to climate; (d) leaf size, shape, surface area, and symmetry; and (e) comparisons of age, ring width, climate, and trunk diameter across tree species. As they presented their ideas, they noted the occasions in which mathematical principles and procedures were used to understand the science involved in tree growth. They reported that the central mathematical topics explored (and, in fact, necessary) in the unit included various forms of data collection and recording, data representation in the form of charts, graphs, scatterplots and tables, ratios and proportions, functions, correlation coefficients, geometry concepts such as perimeter and area, descriptive statistics, and some aspects of probability.

Participants' Reflections on the Collaborative Projects.

Despite their initial hesitations about collaborating, the participants expressed surprise at the success of their work together, as well as the depth of the activities they had created. For example,

> I never experienced mathematics and science taught so that definite connections were made between the two....The experience helped me realize the possible connections/projects that could come out of working with other teachers. I would suggest devoting more time to our projects to come up with more detailed plans and projects. It seemed like we were only able to scratch the surface with our ideas (Michael, Cohort 1; written reflection).

Several participants concluded their reflections by stating their intent to take what they learned through the experience and apply it in their future classroom teaching. As one prospective science teacher offered, "This activity was a good introduction into how we will be expected to work not only with the faculty in our department, but also across disciplines. For me, this was probably the one thing I gained most from the experience" (Anne, Cohort 1; written reflection).

Student Teaching: Efforts Toward Connecting Mathematics and Science

The final aspect of this study was to document efforts the prospective teachers made to connect science and mathematics lessons during their student teaching experiences. First, examples are described of mathematics student teachers who attempted to use scientific contexts as connecting points for mathematical explorations, followed by similar examples of science student teachers who sought to integrate mathematics into their science lessons. Finally, examples of collaborations between science and mathematics student teachers are described.

Mathematics teachers' efforts toward connections. In reporting on their student teaching experiences, several mathematics student teachers noted their surprise at how often they were able to use science in their classrooms. As one reflected, "I used more science than I thought I would, and I have probably used science more than I can even remember" (Michael, Cohort 2, journal reflection). In most cases, the student teachers discussed the value of using science to provide "real world" examples of instances in which mathematical tools and principles were relevant. For example, one participant described her use of Punnett squares in biology when introducing ratios and proportions in an Algebra I class. Another student teacher began to search for scientific models to enrich the algebraic concepts they were studying. He recalled one lesson in which students began the class period by making paper airplanes:

> One day I tied in airplanes and flight with a mathematics lesson. We talked about plane engines, how planes get off the ground, shapes of wings, and the physics behind it all. Tying the two areas together [mathematics and science] with examples like this really helps the kids get involved and understand. (Josh, Cohort 1; interview).

Admittedly, one might question whether or not making and flying paper airplanes as a component of a mathematics and science lesson constitutes meaningful instruction. It could quite easily be the case that students simply thought of the airplanes as a "fun" classroom activity. Yet, this is a notable and important example for consideration. Conceivably, the student teacher could have simply pushed ahead with the mathematical concepts of the day without attempting to provide any meaningful context to support and motivate students' learning. Given that this episode came in the classroom of a student teacher only several weeks into his solo teaching experience, it is significant that he chose to embed the mathematics at hand in a scientific context. Regardless of how superficially the science of flight was treated, this example nevertheless represents evidence that this beginning teacher was concerned enough about finding connections between science and mathematics to incorporate the paper airplanes into the lesson. Such an attempt would likely not have occurred if not for the emphasis on connections made throughout the teacher preparation process.

Another student teacher designed a week-long unit entitled "Endangered Manatees." The intent of the project was for students to examine the decline of manatees in the wild as related to increased human activity and recreation on ocean waters. Two lessons in this unit were observed by the researchers. As the student teacher described in an interview, "I had students research relevant facts about manatees and also gave them data about powerboat registrations and manatees killed per year." Based on these findings, students were then to use statistics to make an argument as to whether or not increased boating and human activity in the natural habitat of manatees were responsible for their decline. Significant about this activity was that students were using mathematics to explore a social issue that was nested within a scientific context. The student teacher spoke to these connections as she reflected,

> This project was successful and worked well in the context of my mathematics class, but would have been more powerful if it had been combined with a study of manatees in a science class (even a social studies class – it is, after all, a social issue as well!). There is much room for extension and enrichment, and it has the potential of being a lot more than just a study of statistics. (Lesson observation interview)

Science teachers' efforts toward connections. Perhaps to even a greater extent than did the mathematics student teachers, the prospective science teachers noted the importance, if not the inevitability, of addressing connections between mathematics and science in their student teaching experience. In a number of journal entries and postlesson interviews, the student teachers indicated that they often simply could not avoid including mathematics in their lessons. As one science student teacher engaged in the teaching of a physical science class noted, "My field experience has really given me the needed dose of reality regarding the frequency of mathematics and science connections at the middle school level. Every day is a science-mathematics connection for me in my eighth grade Physical Science" (Sean, Cohort 1, journal reflection).

Consistently, the student teachers were often surprised at how easily they connected mathematics and science concepts in their classrooms. As one individual reported, "One thing I have found out through student teaching is that it is fairly easy to integrate...After the methods class, I have been consciously aware of what kinds of connections I can use in my lesson planning" (Sheri, Cohort 2, journal reflection).

A number of participants provided specific examples of instances in which they were able to connect mathematics and science. One student teacher described a unit on Work, Energy, and Power by stating that "this was a heavily filled mathematics unit. We worked with unit conversions, problem solving, and equation manipulation" (Mary, Cohort 1, journal reflection). Another student teacher described the mathematical tasks inherent in her unit on weather prediction when she explained how students had to estimate distances, use various mapping scales, and apply the use of formulas to explore relationships between temperature and altitude. A third student teacher engaged his biology students in a lab on disease transmission. As he reported,

> I presented a way that the students could predict how many incubation periods it would take for every student in the room to get infected. I thought this would be a good way for students to see how scientists use mathematical models to predict the spread of disease. (Michael, Cohort 1, journal reflection)

These examples indicate how the prospective science teachers often viewed mathematics as providing the tools for examining scientific phenomena. This perspective might be contrasted with the perspectives of the mathematics students who tended to see science as a means for providing "real world" examples for the mathematical principles at hand.

Evidence of collaborative activity. There were encouraging signs of collaborative efforts throughout the student teaching experience. Most common were instances in which the student teachers discussed possible areas of overlap between their classes and then made efforts to spend a portion of class time discussing mathematics and science connections. For example, one pair of student teachers described their work together as follows:

> One goal that [Jenni] and I share is to convince our students that mathematics and science are inextricably linked together. The sharing of problems between our classes furthers that goal...The day after I present an activity, Jenni will often use the same or similar mathematics problems for her 5-minute warm-up activity. This reinforces the mathematics skills for the students who struggled with the mathematics in science class, and it also gives the kids a chance to feel successful in mathematics class. (Lorrie, Cohort 2, postlesson interview).

Another pair of student teachers used weekly mathematics journals for their students to describe reactions to and explore connections between mathematics and science learning. As the science student teacher reported,

> Questions we have used include: How do professional scientists use math? Does mathematics make science easier or harder? What is the relationship between mathematics and science?...What kinds of science activities require math?... I am convinced that the journals are constructive. (Sarah, Cohort 2, written reflection).

One final example reveals a more significant collaborative effort between two student teachers placed in the same middle school. Early in the field experience, these two participants requested help in thinking about ways in which they might work closely on their respective units. They presented an outline detailing an eighth-grade integrated mathematics and a life science unit on invertebrate and vertebrate species. The plans detailed their intent to use data about attributes such as body mass, reproductive rate, life span, speed, and metabolic rate in order to examine correlations between animals within different phyla or classification groups. Their intent was to help their students draw conclusions about vertebrates and invertebrates based on their use of mathematical tools, procedures, and arguments. In addition to using data analysis strategies to organize, compare, and analyze various data for each species, mathematical concepts covered in the unit included the use of exponents (related to metabolism), exponential growth, graphing, proportions, inverse relationships, and the application of various mathematical formulas.

Moving toward collaboration: Impressions and concerns. These examples of integration are quite remarkable when one considers the challenges already facing student teachers. Despite the pressures and constraints that many student teachers face in working with their cooperating teachers (Frykholm, 1996), these examples point toward the convictions that these student teachers held about the importance of connecting science and mathematics.

Yet, as the student teachers endeavored to create significant overlaps in mathematics and science in their own classrooms, several notable concerns arose. Primarily, the students realized not only the importance of content knowledge in mathematics and science, but the need to develop appropriate pedagogical strategies to address these overlaps in content. As one science student teacher reported, "I soon realized that I needed to learn some effective mathematics teaching strategies" (Michael, Cohort 2, written reflection). This desire to learn effective teaching strategies in both mathematics and science led several student teachers to seek the advice of experienced teachers in their schools. They soon found, however, additional constraints that made meaningful connections of mathematics and science even more challenging. Central to their concerns were issues of time and school structure. As one science student teacher noted,

> [Collaboration] takes time, both in conversation and observation. Time is probably one of the biggest roadblocks for collaborative efforts. It is hard to find time during the day to talk, and even harder to get out of your own classroom to watch other teachers. This is certainly an argument for teams, with their common planning periods. (Sarah, Cohort 1, journal reflection).

Another mathematics student teacher commented about the difficulties inherent in her attempt to engage in a collaborative effort.

> The group of students that I am working with now would benefit so much more from a block schedule and team teaching. Mrs. [Smith] and I could do a lesson that would incorporate both mathematics and science. We could take up two periods and really try to reinforce correct procedures and methods. Unfortunately, her trailer is on the other side of the school. It would be virtually impossible for us to work together at the same time with the same group of students. (Megan, Cohort 2, journal reflection).

Other participants were particularly insightful as to more subtle barriers that prevent teachers from providing connected science and mathematics instruction for their students. In the excerpt that follows, this student teacher recognized the degree to which successful collaboration requires similar philosophies and commitment from participating teachers.

> I think that it is absolutely essential for both teachers to have similar goals in mind. I can collaborate with Nancy [fellow student teacher] because we both aim to teach in a constructivist style. On the other hand, neither of us can truly collaborate with our cooperating teachers, who have very different aims. We can team-teach, but even the [Mr. Boyle (cooperating teacher)] is pushing students to come up with the right answers and to conform to his strict behavioral standards, rather than encouraging them to take time to struggle with concepts or even to record "wrong" answers on the way to a more complete understanding. (Amy, Cohort 2, written reflection).

Amy later reported that the cooperative efforts among teachers in her team were "almost entirely related to student behavior management and parent relations, because our team members either have different instructional philosophies or attach little value to collaboration itself." These astute observations about barriers to integration are notable. That student teachers would already be thinking critically about barriers to integrated instruction seems to be a positive indication of the success of the program.

Conclusions and Implications

Despite the numerous references to connecting mathematics and science instruction in the reform literature, there is a conspicuous absence of empirical studies that help teachers and teacher educators think about how such efforts might actually take place in schools and teacher education programs. The findings of this research, therefore, appear worthy of discussion inasmuch as they have implications for future developments in the effort to connect science and mathematics pedagogy in teacher education programs. Although it was not our original intent to look beyond the immediate context of this project (e.g., following teachers into the classroom to observe their planning and implementation after the preparation program), the importance of further studies that would take aim at such topics now seems evident. In the ensuing discussion of the findings of this research, therefore, remarks are situated within the context of the theoretical perspectives presented at the beginning of this paper, in an effort to stimulate thought about what might be profitable ways to extend both the program and research shared in this article.

Isolation and Fragmentation: The Necessity of Situativity

What was evident about the participants as they entered the study was that they had rarely experienced as learners the kinds of instruction that connects science and mathematics as advocated in the reform literature. Although these preservice teachers were well aware of the importance of advancing mathematics and science connections, they were also quite clear in stating that they had rarely, if ever, seen or experienced such teaching. A common statement was that their mathematics classes, for example, tended to be taught independently from other courses – both other mathematics courses as well as science courses. Moreover, the content was typically fragmented, often taught in isolation from other topics that may have provided various contexts and/or connections.

These experiences impacted the student teachers' thinking as they approached the collaborative methods class sessions. Several individuals felt intimidated because they knew that they had never engaged in the kind of thinking (much less teaching) that they were being asked to produce and, therefore, were uncertain as to how they would function in their groups. Moreover, the isolation they experienced as learners of mathematics and science heightened concerns about their own content knowledge as a prerequisite for rich, contextualized instruction.

These findings certainly echo the concerns of Lederman et al. (1994) – that preservice teachers' conceptions of mathematics and science are based largely on classroom experiences in which topics and concepts were fragmented, introduced in the absence of meaningful contexts, and taught in isolation of one another. The situative lens of connecting to real world experiences and scientific research would certainly seem to hold promise as a way to avoid the common anxieties and gaps in understanding that these prospective teachers brought to the experience. Notable about the instructional model promoted in this research were the ways in which these students overcame these initial dispositions toward fragmented and narrow conceptions of mathematics and science as they collaborated in authentic planning and delivery of integrated units of instruction.

Beyond Barriers of Knowledge and Belief: Context as the Vehicle for Understanding

By their own reports, the participants questioned their ability to implement connected mathematics and science instruction, largely because they felt their content knowledge in one (or both) of these disciplines was insufficient. Although it was more common for the prospective mathematics teachers to suggest that their science background was weak, several science teachers also made similar statements about their deficiencies in mathematics. This finding should not cause great surprise. Indeed, the research literature contains numerous examples of preservice teachers who do not have adequate content knowledge in their own fields, much less in an additional content area. As noted previously, most prospective teachers have rarely experienced as learners richly connected ideas and concepts in mathematics and science classrooms. Indeed, in isolation, many student teachers were frustrated by their inability to articulate ideas and activities that illustrated the links between mathematics and science.

One response to these deficits in knowledge would be to require prospective mathematics and science teachers to take additional coursework so that their knowledge of both mathematics and science would be sufficient to promote teaching both subjects. Doing so within the framework of most traditional teacher education programs, however, remains problematic. Moreover, as a number of scholars have noted (see Adams & Krockover, 1997; Shulman, 1986), research findings continue to suggest that increasing academic coursework in science and mathematics "will not guarantee that teachers have the specific kind of subject matter knowledge needed for teaching" (Floden, 1993, p. 2). Hence, the findings of this study are valuable in the sense that they point to an alternative method of increasing beginning teachers' ability to overcome deficits in their knowledge of mathematics or science through engagement in active learning opportunities in which authentic contexts provide fertile ground for understanding mathematics and science connections.

By focusing on pedagogical context knowledge, the potential problems inherent in the student teachers' deficiencies in content knowledge dissipated as they collaborated, shared ideas, and helped each other with fundamental concepts and procedures that emerged as more general, realistic contexts were discussed. As Berlin and White (1995) argued, efforts to integrate mathematics and science should be founded, in part, on the idea that knowledge is organized around big ideas, concepts, or themes, and that knowledge is advanced through social discourse. Berlin and White's idea – that knowledge is advanced through social discourse – speaks directly to the assertion that effective connected instruction requires the development of socially mediated and contextualized knowledge structures. As prospective teachers in this study worked together on the development of units that were centered on broad scientific themes or concepts, and as they engaged in social interactions and contributed to the discourse in their small groups, they made significant gains in their own understandings of connections between mathematics and science. They also appeared to gain confidence and eagerness to focus more intently on making curricular connections.

A Potential Model for Teacher Preparation

Recent findings have suggested that preservice teachers rarely experience as learners the type of instruction and professional responsibilities they are expected to perform once in the schools. This certainly appeared to be the case in this research. At the beginning of the study, the participants frequently commented about how seldom they had seen or experienced teaching that specifically connected science and mathematics. Yet, they also reported feeling some pressure to implement integrated instruction as articulated in the reform literature to which they were exposed in the preparation program. Quite clearly, they were in a difficult position – they believed that they were supposed to connect mathematics and science in their teaching, but they had seldom seen or experienced such models of instruction.

One of the primary strengths of the model promoted in this research was that it gave these prospective teachers an opportunity to experience the kind of instructional models we hope they will one day implement in their own classrooms. Learners actively construct ways of knowing as they strive to reconcile present experiences with existing knowledge structures. If this applies to children's learning, it also applies to the learning of prospective teachers as they engage in the process of acquiring knowledge about teaching.

Our intent was to "situate" the learning of these students by creating an opportunity for our prospective mathematics and science teachers to work together, to share ideas, to collaborate, and to participate in conversations about connecting science and mathematics. In short, we wanted to allow them to construct their own understandings of the links between science and mathematics by engaging in collaborative groups – much like we hope they will provide for their own students. Moreover, the collaborative planning in which the participants engaged was a model for the type of cooperation and team-teaching that many of these teachers will be expected to perform once in the school setting.

Points of Consideration for Further Inquiry

Clearly, this project generated enthusiasm for connecting science and mathematics instruction among the participants. The products of their collaborations indicated that they were able to build upon their knowledge bases to create significant learning opportunities for learners. Despite the positive findings of this study, we were left with several questions and points of consideration that inevitably will continue to be a part of discussions regarding the preparation of teachers for connected teaching in these fields.

First, the number of the prospective teachers who had never had experiences with connected mathematics and science instruction prior to the student teaching was notable. Though they lacked this experience, they nevertheless reported having strong beliefs that this kind of connection should indeed happen in schools. What, then, is the relationship between these two seemingly disparate statements? Future research could more closely examine these various points of view.

A second, and perhaps more critical issue focuses on the uses of mathematics in the curriculum units developed by the groups. What appeared to surface regularly in the projects was the notion that mathematics is a tool to collect data, to represent data, and to be used for computational purposes. This perception of "mathematics as tools" may fall short of how some in the mathematics education community define mathematics and promote its study in the K-12 experience. One might argue that the ways in which the mathematical ideas in these projects were often manifest as "tools" might leave students short of understanding the underlying conceptual and mathematical systems framing the tools. However, when mathematical tools are viewed as mathematical inscription devices (Roth & Bowen, 1994) – that is, graphs, charts, equations, etc. – they are perceived as authentic socially constructed, negotiated, and legitimated devices. Moreover, these tools represented perfectly appropriate uses of mathematical principles and concepts in the context of using science. These findings point toward the need for continued exploration into the use and role of mathematical tools as inscription devices in science curricula.

Third, what continues to be an obvious question at the conclusion of this study is one of content knowledge. If teachers are to connect science and mathematics, what prerequisite knowledge bases must they have, and what experiences best provide them? One option is to require more content coursework in mathematics and science. A growing number of institutions are offering integrated programs leading to licensure in science and mathematics, particularly at the middle school level. At the middle school level, many teachers must demonstrate competence in two teaching fields and be actively engaged in interdisciplinary teaching. In contrast, the high school curriculum is primarily organized around disciplines with little incentive to connect the subjects. For the majority of students in more traditional secondary teacher preparation programs, it remains unlikely that they will have the time and inclination throughout their course of study to take the additional coursework necessary for endorsements in a second teaching field. How, then, can methodology courses be designed to provide a context for understanding and promoting the connections between mathematics and science?

In summary, it is evident that the task of providing rich experiences for future teachers to develop prerequisite knowledge and experiences necessary for connected science and mathematics instruction continues to rest largely on the experiences provided within the context of the teacher preparation process. Despite the limitations and unresolved questions, the research presented in this article has a significant contribution to make in that direction. The emphasis on contextualized interaction in this program included opportunities for these prospective teachers to experience a model of reform pedagogy as learners and to participate in collaborative activities that we hope they will implement in the school setting.

These preservice teachers not only learned about collaboration, they also grew in their knowledge of the connections between science and mathematics. In a sense, these prospective mathematics and science teachers became consultants to one another as they explored ways to situate mathematics in relevant contexts, as well as ways to mathematize scientific phenomena. This research suggests that teacher education programs can be the site where these fundamental issues related to the connections of mathematics and science can be explored with the potential for great success. It may be the case that this model of teacher education, or others like it, embodies, at least in part, what Fennema and Franke (1992) had in mind when they suggested a "total reorganization of both schools and teacher education programs" (p. 160).

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