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Perceptions of Making Connections Between Science and Mathematics in a Science Methods Course

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Abstract

The integration of mathematics and science is a recommended pedagogical strategy made by major reform-based documents. The goal is to enhance learner understandings by recognizing the relationships between the two disciplines. Documented attempts to systematically enact this initiative in teacher preparation remain uncommon. As a result, an elementary science methods course instructor in collaboration with two mathematics education researchers conducted a practitioner-research study that examined his efforts to connect mathematics and science. The perceptions of two groups of interns (those in a specialized program that aimed to make connections between mathematics and science and those who were not in the program but who were concentrating in mathematics or science) were contrasted in regards to the following four elements: (1) an appropriate science learning environment for elementary students, (2) the extent to which their science methods instructor modeled good teaching of science, (3) the extent to which they observed their science methods instructor making connections to mathematics in his teaching, and (4) the rationale for and intent to make connections between science and mathematics in elementary teaching. We found that there were discernible differences between the two groups in their perceptions about the issues under study. An implication for practice is that caution should be exercised when attempting an integrated approach to a science methods course, since interns may perceive the discipline of mathematics in a limited manner.

Introduction

This practitioner research study (Hollingsworth, 1997) interprets the efforts made by one elementary science methods instructor to make connections between mathematics and science in an elementary science methods course. Within the science and mathematics education research communities, there has been longstanding interest in the notion of the integration of mathematics and science and how teachers should be prepared to enact this in their classrooms (McComas & Wang, 1998; Roebuck & Warden, 1998). McComas & Wang (1998) state that the goal of this initiative in teacher preparation is to help teacher interns recognize the relationships between the two disciplines, and as result, become more effective teachers (p. 332). Documented attempts to systematically enact this initiative in teacher preparation remain uncommon; therefore, an elementary science methods course instructor in collaboration with two researchers decided to conduct a practitioner-research study

(Kemmis & McTaggart, 2000) that examined his efforts to connect mathematics and science in his practice.

This study presents interns' perceptions of the degree of interaction within curriculum and instruction of mathematics and science in an elementary science methods class. Researcher assertions are included (one of which is the course instructor's). Research focuses on seven teacher interns who participated in a special undergraduate teacher preparation program funded by the National Science Foundation (NSF), the Maryland Collaborative for Teacher Preparation (MCTP), as well as a comparison non-MCTP group consisting of four elementary education majors with concentrations in mathematics or science.

Literature Review

In preparation of the innovation to make connections between mathematics and science in the science methods course, a review of the literature was conducted. The objective was to determine what was promoted in the literature as rationales for making connections between the disciplines and theorists' level of knowledge concerning such an innovation. In particular, two areas were examined: (1) professional associations' call for mathematics and science integration and (2) theoreticians' conceptualization of mathematics and science integration. McGinnis's (the elementary science methods instructor) intention was to use the information from the survey of the literature to inform his thinking about making connections between mathematics and science and to obtain information that he could share with his teacher interns.

From a review of professional associations' call for integration of the disciplines, we learned that professional associations concerned with the teaching of mathematics and science have long called for the integration of the disciplines. In particular, The School Science and Mathematics Association (SSMA), the National Council of Teachers of Mathematics (NCTM), and the American Association for the Advancement of Science (AAAS) have taken a leadership position. Indeed, faced with a burgeoning body of work on the integration of the two school disciplines, it was decided in 1905 to publish a bibliography of the literature on that topic to assist interested professionals. Influential documents such as *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989), *Science for All Americans* (AAAS, 1990), *Benchmarks for Scientific Literacy* (AAAS, 1993), the *National Science Education Standards* (NRC, 1996), and *Principles and Standards for School Mathematics* (NCTM, 2000) all promote linking the teaching of the two disciplines.

From a review of the theoreticians' conceptualization of mathematics and science integration, we found Berlin's (1991) and Berlin and White's (2001) comprehensive bibliographies on the integration of mathematics and science helpful in beginning our literature review search in this area. We were surprised to learn from Berlin's and White's reviews that research had played a subsidiary role in the published examination on this topic. Earlier, in discussing her review of the literature, Berlin (1994) stated that there existed a "marked paucity of research documents" (p. 32) with only 41 of the 555 citations relating to research. She stated there was a need for "conceptualization and additional research on integrated science and mathematics in teaching and learning" (p. 4).

Most helpful for our purposes was Berlin and White's finding of how science and mathematics had been most commonly presented in attempts to integrate the two disciplines. As Berlin reported, . . .

> The science processes of classifying, collecting and organizing data, communicating, controlling variables, developing models, experimenting, inferring, interpreting data, measuring, observing, predicting, and space-time relationships were most frequently cited in the instruction literature. The most frequent mathematics concepts/skills mentioned or implied include angular measurement, estimation, formulas and equations, fractions, function, geometry, graphs, modeling patterns, percentage, probability and statistics, problem solving, ratio and proportion, and variable. (p. 4)

We also found an empirically informed study conducted in 1988 by Lehman and McDonald that was designed to assess whether an integrated approach to teaching mathematics and science would change teacher interns' teachers' perceptions toward integrating the two disciplines. Also, the researchers compared prospective teachers' (in the integrated program) and practicing teachers' perceptions of mathematics and science. They found that prospective teachers increased their awareness of curricular materials for math/science integration and believed that integrating mathematics and science was a preferable method for teaching. Lehman and McDonald posited that the student teachers developed a more sophisticated definition of integration after starting the semester with an oversimplified definition of integration. They also found, however, that mathematics student teachers changed their thinking in the reverse direction. This change was attributed to possibly recognizing some activities as integrated under a more sophisticated understanding of integration, or possibly recalling some activities that they previously had not.

Another influential theoretician who examined this research area was McBride (1991, who discussed a rationale for integrating mathematics and science. The following four reasons were given:

> (1) Science and mathematics are closely related systems of thought and are naturally correlated in the physical world. (2) Science can provide students with concrete examples of abstract mathematical ideas that can improve learning of mathematics concepts. (3) Mathematics can enable students to achieve deeper understanding of science concepts by providing ways to quantify and explain science relationships. (4) Science activities illustrating mathematics concepts can provide relevancy and motivation for learning mathematics. (pp. 286-287)

Steen (1994) discussed five possible ways to integrate mathematics and science: (1) using mathematical methods in science, (2) using science examples and methods in math instruction, (3) teaching math entirely as a part of science, (4) teaching science entirely as a part of mathematics, (5) employing math methods in science and science methods in math, coordinating both subjects. Steen described each of these options and pointed out that while mathematics and science can contribute to each other, the two disciplines are "fundamentally different enterprises" (p. 9). He stated that "science seeks to understand nature, [and] mathematics reveals order and pattern" (p. 9). He concluded, therefore, that an effective educational program must teach students the ways not only in which mathematics and science are similar, but also the ways they are different. Steen questioned whether it was possible "to teach an entire curriculum that integrates science and mathematics" (p. 10). He stated that it was not possible because science and mathematics teachers were not sufficiently prepared to understand mathematics and the multiple sciences within science (e.g., physics, biology, and chemistry). To avoid this overwhelming constraint to successfully integrating mathematics and science, Steen suggested that instead of attempting to integrate content, practitioners should integrate instructional methodologies (e.g., exploratory, investigative, and discovery learning).

Lonning and De Franco (1997) supported Steen's recommendation. They proposed a continuum model of integration as a tool for curriculum development and for modifying lessons to enhance math and science connections. They cautioned that not all mathematics or science concepts could or should be taught through integration. Instead, they recommended attention be directed toward, "'How can the concepts best be taught?' rather than 'How can they be integrated?'" (p. 215).

Context of the Study

The Maryland Collaborative for Teacher Preparation (MCTP) was an NSF-funded statewide undergraduate program for teacher interns who aspired to become specialist mathematics and science upper elementary or middle level teachers. The MCTP was one project in the NSF Collaboratives for Excellence in Teacher Preparation Program (CEPT). While MCTP interns were generally indistinguishable in level of academic achievement from other elementary teacher interns with concentrations in mathematics and science, they did distinguish themselves from all other interns by taking 36 hours of mathematics and science courses (18 hours of each discipline). In many cases, the content courses (open to all teacher interns) had been reformed to conform to the MCTP program goal. Non-MCTP elementary teacher interns who chose to emphasize mathematics (only) were required to earn 18 credits in mathematics and 8 in science. Interns with a science (only) emphasis were required to earn 18 credits in science and 11 in mathematics.

The goal of the MCTP was to promote the development of teachers who were confident teaching mathematics and science, who could make connections between and among the disciplines, and who could provide an exciting and challenging learning environment for students of diverse backgrounds. As such, goals included introducing prospective teachers to standards-based models of mathematics and science instruction and providing courses and field experiences that integrated mathematics and science. In practice, the MCTP undergraduate classes were taught by faculty in mathematics, science, and education, who strived to diminish faculty lecture while emphasizing student-based problem solving in cross-disciplinary mathematical and scientific applications.

Research Question

Since the goal of the study was to gain additional insight into the perceptions of differing types of interns (MCTP and non-MCTP) regarding the elementary science methods instructor's pedagogical innovation to make connections between mathematics and science, the following central research question was investigated:

Were the MCP teacher interns distinguished from the non-MCTP teacher interns in the beliefs and perceptions upon completion of the science methods course concerning the following four elements?: (1) an appropriate science learning environment for elementary students, (2) the extent to which their science methods instructor modeled good teaching of science, (3) the extent to which they observed their science methods instructor making connections to mathematics in his teaching, and (4) the rationale for and intent to make connections between science and mathematics in elementary teaching.

Research Design

Methodology and conceptual framework. This is a practitioner research study using an N of one (a case study). A common focus of practitioner-research is to promote a self-reflective analysis that can improve teaching practice and our understanding of practices (O'Hair, 1995). This case study involved a cycle of four steps: (1) planning, (2) enacting, (3) observing the plan, and (4) reflection (Carr & Kemmis, 1986).

We chose a case study (Stake, 2000) because we were interested in describing and interpreting the personal constructions of the college instructor and his coresearchers as the instructor examined his practice in the context of infusing innovation. For this study, the case is bounded by a unit of analysis that provides guidance on what is relevant and not relevant (Merriam, 1988). The unit of analysis is the interdisciplinary (mathematics and science) innovation of the one semester course.

The symbolic interaction theoretical stance makes the assumption that social reality is a social production (Blumer, 1969; Denzin, 1978). Meanings are constructed by humans through interaction; meanings are not inherently linked to inanimate objects or events. A central premise is that inquiry must be grounded in the empirical environment under study. This theoretical position places emphasis on the social construction of meaning in a culture through viewing the process of how individuals define and interpret each other's acts. In this study, the symbolic interaction theory provided guidance for the roles of the researchers and the interpretative domain of the study (Goetz & LeCompte, 1984). The instructor, who was engaging in a self-experimentation (Dandy & Boring, 2005) of his teaching practices, believed that the symbolic interaction theoretical stance supported the case study methodological approach as well as his interest in hearing the perspectives of the learners in his course. Qualitative research assumes that there are multiple realities constructed as a function of personal interaction and perception (Merriam, 1988).

Data collection strategies. Participants included the instructor of the science methods class (McGinnis), two co-researchers with expertise in mathematics education (McDuffie and Graeber), and select teacher interns in the course. Participating interns included the MCTP teacher interns (six female; one male) and four non-MCTP teacher interns (three female; one male) with concentrations in mathematics (n=2) or science (n=2).

Since the primary researcher of the study was the course instructor, McGinnis relied on McDuffie who was not associated with the course to conduct an end of the semester interview with the participating interns (see Appendix). McGinnis hoped that by separating himself from the collection of the interview data (but not from the analysis of such data that were masked to protect the anonymity of the participants), that his interns would be more likely to express candid perceptions.

In addition, after completion of the individual semi-structured interviews, McGinnis and Graeber conducted an open-ended, large group discussion with the seven MCTP teacher intern participants. McDuffie videotaped this discussion. The discussion was prompted with an initial question read by the course instructor, "What attempts have you observed your science methods instructor making to establish connections between mathematics and science in your science methods courses?," and from that prompt, a conversation transpired that lasted 40 minutes.

McGinnis also kept a journal in which he regularly reflected on the pedagogy of the science methods class.

Data analysis. We collected and analyzed the data through the use of the qualitative technique of analytic induction to construct patterns of perception similarities (Ryan & Bernard, 2000). Since we were interested in the study participants' stated perceptions, we relied on the interns' interview and focus group responses to answer our research question by subsections. Our aim was to compare the end-of-the-semester MCTP teacher interns' perceptions with the perceptions of the four non-MCTP teacher interns with similarly strong backgrounds in mathematics and science but who had not taken any of the MCTP reformed-based content classes.

We constructed our assertions by carefully reading all the participant responses to our inquiries with the aim of detecting patterns that were essential to our purpose. McGinnis took the lead in the analysis by sharing his tentative assertions (supported by sample intern quotes). The final versions of the researcher assertions (as well as selection of the intern quotes to report in support of the assertions) were negotiated by all of the researchers in an iterative manner.

Trustworthiness of the data. Criteria to enhance the trustworthiness of the data analysis were based on methods described by Eisner (1991), Erickson (1986), Guba and Lincoln (1989), and Janesick (2000). These methods included the qualitative warrant checks of long-term observation in a setting, collection of data from multiple sources, and respondent reactions.

The Pedagogical Innovation

The three-credit elementary science methods course examined in this study was taught in the fall semester at the University of Maryland, College Park. The science methods class was taught in a manner consistent with the education philosophy of the instructor. McGinnis chose to place emphasis on the construction of science content in conjunction with knowledge construction in science education theory. Science education topics that formed the substance of the course included the following: concept mapping, the nature of science and science teaching, inclusive science education practices, the fair test, the learning cycle, science process skills, safety, alternative conceptions, alternative assessments, science talks, and science-technology-society and socio-scientific issues. In practice, the teacher interns in McGinnis's course began each session in small cooperative learning groups that engaged in a student-centered, problem-based science learning activity that serves as a referent during subsequent pedagogy discussions facilitated by the instructor. The activities were selected to represent different grade levels, all the sciences, and connections with other disciplines, particularly mathematics. McGinnis facilitated discussions by posing questions that unpacked the pedagogical implications inherent in the activities.

The teacher interns were assessed by their ability to complete the following: research a science content topic, interview young learners on their conceptions of the topic and report their findings in a concept map and a brief narrative, carry out instruction (and reflect on that experience) in an elementary school setting, carry out an inquiry investigation and present it to the class in a poster format, and write an end-of-the-semester essay in which they demonstrate how inquiry investigation aligned with science education standards.

From the review of the literature on making connections between mathematics and science, McGinnis confirmed that his intent to make connections between science and mathematics in the science methods course was timely and supported by recommendations made by both professional associations and theoreticians. In a journal entry written before the study semester, he outlined how he planned to enact his pedagogical innovation:

> I plan to highlight connections between science and mathematics in my MCTP science methods course. Based on my understanding of the literature, I have decided on specific ways I intend to accomplish this innovation. Firstly, I will examine with my learners the role of problems in teaching mathematics and science. Throughout the course, we will collect data in problem-driven activities. I will discuss how the investigative method is a recommended instructional methodology in both reform-based mathematics and science. The graphing of data in these activities (e.g., dropping a bouncing ball from differing heights and measuring its rebound height from the floor) will also offer a rich context in which to explore the way mathematics is connected oftentimes in science as a way of graphical displaying data. I foresee a meaningful connection between mathematics and science when we discuss the shared and differing graphical conventions in mathematics and science (i.e., axes labeling and connections of data points). Secondly, I will give my learners peer conversation assignments in which they will be encouraged to make connections among the sciences and between science and mathematics. I encourage my learners to perform these student-centered activities with young learners in their field assignments this semester, but require them minimally to do so once in a structured assignment. To prepare them to discuss in a more informed manner connections between mathematics and science in their activities, in a lecture I will provide them with a summary of the literature review and highlight the continuum models discussed by Lonning and De Franco (1997) as useful curriculum planning tools. Thirdly, I will help them assess the pedagogical benefits of the connections among the sciences and mathematics they see demonstrated in their science methods course and in their field placements.

Throughout the semester, the instructor took the following four actions to enact his pedagogical innovation to make connections between mathematics and science:

1. He focused on the cognitive/constructivist view of teaching. He began the semester modeling how the teacher interns could teach young learners the phases of the moon in a problem-based, interdisciplinary (mathematics and science), cooperative learning, and technology-rich manner. He continued modeling exemplary pedagogical practices throughout the semester in many other learning activities.
2. He used the text *The Young Child as a Scientist: A Constructivist Approach to Early Childhood Education* (Chaille' & Britain, 1997) as one text to support

the cognitive/constructivist perspective of the MCTP; he used *Science in the Multicultural Classroom* (Barba, 1995) to support the MCTP perspective on diversity; he used the *National Science Education Standards* (NRC, 1996) and *Benchmarks* (AAAS, 1990) to support the emphasis on the standards movement in science education; and he used *Talking Their Way into Science* (Gallas, 1995) to support the emerging concern for classroom discourse in science education.

3. He emphasized reflection on key ideas and conceptual change throughout the course.
4. He made more effort than usual to make connections between science and mathematics. He allocated an entire class session at the beginning of the semester to focus on ideas culled from a review of the literature on the rationale and the ways to make connections between science and other disciplines (particularly mathematics). He highlighted the curriculum integration model (see Lonning & DeFranco, 1997). Throughout the semester, the instructor engaged the teacher interns in conversations on making connections between mathematics and science. He revealed that in his practices he was most influenced by Steen's (1994) recommendation to make connections in instructional methodologies. Consequently, the instructor devoted two additional class sessions to teach a demonstration lesson derived from curricular development work completed by the MCTP faculty, "The Island of Earf" (McGinnis & Graeber, 1994). This simulation module makes links between mathematics and science in instructional methodologies (problem-based and investigatory) as the teacher interns participate as members of health clinics charged with determining the causes and treatment of ear infections on an island. Following this experience, the instructor required the teacher interns to construct a lesson plan in Earth Science that demonstrated how they planned to make connections between mathematics and science. The teacher interns then taught to elementary students in their field placements a problem-driven science activity of their selection/generation that attempted to make connections between mathematics and science. A portion of the teacher interns' assessments of the lesson was to reflect on the manner and effectiveness of their attempts at making connections between mathematics and science.

Results

In this section, we report findings by subsections of the central research question. Two different perspectives are reported: (1) the MCTP teacher intern perspective and (2) the non-MCTP teacher intern perspective. We also report researcher assertions.

An Appropriate Science Learning Environment for Elementary Students?

MCTP teacher interns" perception. The MCTP teacher interns believed that young students should learn science through inquiry characterized by the use of manipulatives, relevance to their lives, cooperative groups, and connection to other subjects. Typical comments included the following:

> *For science I think that students should go through the inquiry process where they predict, and test, and then, you know, reflect and stuff at the end. Provide experiences that the students can use hands-on manipulatives to kind of explore how they think about something and question their own ideas (Mary, End-of-Semester Interview)*

Science should connect to other subjects. It makes it more authentic I guess . . . I think that it's important not to just, you know, find your right answer or the wrong answer, maybe find out how it's applicable, or, you know, how it fits into their lives. (Laura, End-of-Semester Interview)

Non-MCTP teacher interns' perception. The non-MCTP teacher interns believed that young students should learn science in settings in which the teacher played a prominent role as a demonstrator of activities. A typical comment was . . .

Especially with the lower elementary, [the science teacher should] show them, actually physically doing it before they do so they see it . . . Showing them, going through it with them first and say, "Okay. This is what's gonna happen. (Margaret, End-of-Semester Interview)

Assertion. The MCTP teacher interns thought young learners should learn science through inquiry characterized by being connected to other subjects and requiring active student participation. The non-MCTP teacher interns expressed a vision of an appropriate learning environment for young students characterized as being more teacher-centered. We believe this more teacher-centered characterization is a result of the non-MCTP teacher interns having less experience in undergraduate content classes in which the instructors modeled student-centered instruction. In contrast, the non-MCTP teacher interns evaluated the science methods instructor as modeling good teaching practices such as open-ended questioning; however, the non-MCTP teacher interns' evaluations lacked the depth of reflection and analysis demonstrated by the MCTP comments. Moreover, the non-MCTP teacher interns did not link their science methods instructor's practices with the practice of any previous science teacher with whom they had experiences, as did the MCTP teacher interns. Consequently, the non-MCTP teacher interns reverted to the model that was most familiar to them in their own experiences, a more teacher-centered environment.

Extent to Which Their Science Methods Instructor Modeled Good Teaching of Science?

MCTP teacher interns' perception. The MCTP teacher interns identified their MCTP science methods instructor as modeling good teaching by the use of small cooperative groups, engaging student-centered activities, demonstration of various instructional strategies (including making connections between mathematics and science), an emphasis placed on questioning and discussion, and a concern for creating a classroom environment characterized by respect for all. His focus on conducting experiments and discussing personal constructions rather than on memorization of facts was perceived as being in alignment with the instruction they experienced in their MCTP science content classes. Typical comments included the following:

I'm thinking of one, using peer—small groups—peers, and we did a lot of that in his class [the science methods class], when we did our, you know, lesson plans and then our peers would evaluate it, and that was really good. (Mark, End-of-Semester Interview)

> *The simulation type lessons—the ear and the pencil. You know, there were a lot of things [in the science methods class] that truly we could transfer into our classes and use and have, you know, confidence in how that's going to play out. I would also say the investigation, the questioning, not being focused on the answer, and that maybe there are many answers to one question. (Mary, End-of-Semester Interview)*

Non-MCTP teacher interns' perception. The non-MCTP teacher interns identified their science methods instructor as modeling good teaching by making class engaging through the use of activities and demonstrations. His use of predictions especially impressed them. Typical comments from the non-MCTP interns include the following:

> *We did incredible activities [in the science methods course]. He also did demonstrations. (Molly, End-of-Semester Interview)*

> *As he [the science methods instructor] was doing demonstrations, he would, you know, have us think, "What's gonna happen next?" So we did a lot of prediction. It was fun. (Margaret, End-of-Semester Interview)*

Assertion. The MCTP teacher interns described the teaching of their methods instructor in a rich manner that identified many teaching practices that they believed were effective. These practices included the use of small cooperative learning groups, student-centered activities, making connections between science and mathematics, and an emphasis on classroom discourse. In particular, his use of experimentation and an emphasis on the personal construction of knowledge rather than on the memorization of facts were perceived as being in alignment with the instruction they experienced in their MCTP science content classes. In contrast, the non-MCTP teacher interns evaluated the science methods instructor as modeling good teaching practices such as the use of student-centered activities but did not link his practices with the practice of any previous science teachers they had experienced.

Extent to Which They Observed Their Science Methods Instructor Making Connections to Mathematics in His Teaching?

MCTP teacher interns' perception. The MCTP teacher interns identified their science methods instructor making connections between science and mathematics throughout the semester. They recognized that specific activities, including one designed as an MCTP module on ear infections, were used by the instructor to achieve that goal. It was also recognized that he allowed them to make connections with mathematics in all their class assignments. Typical comments included the following:

> *Well, with the ear lesson, that was kind of, it went hand and hand—math and science—and then he made connections to language arts with the . . . the (Oh, I can't think of it.) . . . the bus, the "Magic School Bus" book and, then the Science, Technology, and Society topic. . . . We did the investigation with the ear. Oh, with our lessons we prepared in science methods, we were encouraged to integrate mathematics. I now think that in so many aspects of science, you are using math to either solve the problem or analyze the data or, you know, somehow relate it. (Laura, End-of-Semester Interview)*

In the beginning of science methods, he gave us the bouncing the ball lesson. We did graphs. Our Science Investigation, my whole science investigation was math. I would think that there was more integration of mathematics in science methods than was evident in the science in math methods. (Katie, End-of-Semester Interview)

Non-MCTP teacher interns' perception. The non-MCTP teacher interns recognized that their science methods instructor sought to make connections between mathematics and science. They identified a few classroom activities that accomplished this innovation, including the MCTP module on middle ear infections. Typical comments included the following:

To what extent did he seek to make connections between science and mathematics? I would say, like, all the time. For example, the bouncing balls where we had to count how many bounces from different heights. We made graphs. And he even asked how would we tie in the science activities he taught us with math or how could . . . if this was a math class, how could we tie it to a science? For example, when we talked about gravity. (Margaret, End-of-Semester Interview)

That last ear thing we did, the ratios. (Molly, End-of-Semester Interview)

Assertion. Both the MCTP teacher interns and the other teacher interns readily identified instances in which the science methods instructor sought to make connections between science and mathematics. The MCTP teacher interns were distinguished in the greater number of instances that they identified as fulfilling this curricular innovation.

The Rationale for and Intent to Make Connections Between Science and Mathematics in Elementary Teaching?

MCTP teacher interns' perception. The MCTP teacher interns stated that the rationale for making connections between mathematics and science was to more accurately portray a holistic vision of knowledge. Through this portrayal of the world, a deeper understanding was possible. They expressed a commitment to make extensive connections between mathematics and science in their practices. They indicated, however, that the two disciplines should only be connected when it was natural, or appropriate, in the context of a topic under study. They noted that mathematics could be connected to science more frequently, and appropriately, than science to mathematics. Typical comments included the following:

That's the way our world is. Science and mathematics aren't separate. It should be balanced and that they should be dependent on each other if it's possible. It's hard to do, but they really should be dependent, so you couldn't really do one without the other, or it would make it difficult to do one without the other. (Mark, End-of-Semester Interview)

I think it [the lesson] has to kind of really flow and the science and mathematics have to be a real part of each other and not just forced. I think you should always try to because it just makes it that more meaningful, but if you can't, don't force it, you know. That might just turn students off. [In my future teaching] I think I will start off, maybe using some of the examples that we've been given in our classes, the kinds *of lessons that they done, and then possibly moving, you know, more into it as I get more comfortable with it. (Mary, End-of-Semester Interview)*

Well, with the flow I think that making connections between science and mathematics needs to be meaningful . . . for it to be true integration, for it to be meaningful, it needs to be more into the content or the processes of that subject. I definitely like to make connections in my future teaching, but it's not as easy as it sounds, and I think it'll take a lot of more practice. (Laura, End-of-Semester Interview)

Non-MCTP teacher interns' perception. The Non-MCTP teacher interns indicated that science and mathematics were connected by requiring the same sort of thinking processes. While they expressed support for making connections between mathematics and science, they seemed particularly hesitant to make what they perceived as inappropriate curricular connections. Examples provided by them on making connections between the disciplines portrayed mathematics as a tool in science. Typical comments included the following:

Mathematics and science use the same kind of thinking, I mean, use the same kind of thinking processes. However, they should only be integrated in those types of lessons where they reinforce each other. (Molly, End-of-Semester Interview)

I think not all science lessons are gonna have some math in them, so if a teacher just throws the math in there, then it wouldn't be appropriate in all cases. (Lisa, End-of-Semester Interview)

Assertion. The MCTP teacher interns were distinguished from the non-MCTP teacher interns in the more sophisticated manner in which they could articulate a rationale for and intent to make connections between science and mathematics. The MCTP teacher interns supported the curricular innovation to make connections between science and mathematics whenever it was appropriate to more accurately portray a holistic vision of knowledge. Overall, the non-MCTP teacher interns made fewer connections between science and mathematics and were more likely to portray mathematics as a tool when connections were attempted.

Conclusion/Implications

When comparing the perceptions of two groups of teacher interns who shared the common experience of a science methods course that aimed to make connections between mathematics and science, the MCTP and non-MCTP groups differed in the depth and sophistication of their understanding. Consistently, the MCTP teacher interns offered comments that were more developed in the way they explained their ideas of the areas examined in this study, and they provided more specific examples of their thinking as compared to the non-MCTP interns. We speculate that this resulted because the MCTP interns had experienced more of this type of learning environment in their special undergraduate teacher preparation program (and had more opportunities to reflect on their teaching and learning) while the non-MCTP had not. Clearly, the efforts made by the MCTP mathematics and science content instructors to teach in a reform-based manner made a difference in how receptive the MCTP teacher interns were in their science methods course to the pedagogical innovation of making connections between science and mathematics.

In regard to McGinnis's goal of helping interns understand the connections between mathematics and science, he achieved a level of success that resembled the findings by Lehman & McDonald (1988), but we need to consider Steen's (1994) warning. While McGinnis's course did not promote the idea of mathematics only as a tool for doing science, the participating teacher interns did not seem to view mathematics as more than this when discussing the *discipline* of mathematics. Referring back to Steen's notion that the two disciplines are "fundamentally different enterprises" (Steen, 1994, p. 9), this finding serves as evidence that by viewing the disciplines from a connected perspective, a limited view of mathematics can emerge even when that view is not held or promoted by the science methods instructor. When discussing the *processes* of science and mathematics, however, the interns perceived many commonalties (e.g., investigation and problem solving) and demonstrated a more developed understanding of these processes in each discipline. Again, this finding is consistent with Steen's (1994) recommendations that in making connections between mathematics and science, we should focus on the methodologies of the disciplines (i.e., focus on the commonalties of how we do mathematics and science) rather than on *what* is common between mathematics and science.

Therefore, while definitive conclusions about making connections between mathematics and science in an elementary science methods course await additional studies to increase the range of contexts and sample size, data from this practitioner research study suggests that caution should be exercised because there is potential for interns to view mathematics in a limited manner (i.e., only as a tool).

Epilogue One: The Instructor's Reaction

Taking Steen's (1994) suggestion as my organizational principle, I worked throughout the semester to make connections between science and mathematics by seeking linkages among instructional methodologies. I found initially that planning for instances to make connections between mathematics and science required much thought and preparation; however, over the semester, they became more seamless in my teaching practice.

I am now accustomed to ask my teacher interns and myself where curricular connections between the disciplines would be appropriate in the teaching of science. It is an ongoing process that requires commitment to proceed but offers many opportunities to enhance instruction. For example, many semesters, I taught the phases of the moon as an example of reform-based science without making any significant connections to mathematics. I made an effort to discuss the changing times of moonset and moonrise and the changing nature of the calendar dates for the phases—instances in which numerals were used—but that was as far as I went in making connections between science and mathematics. During the study semester, I wondered how it would influence my instruction if I numbered the photographs of the phases of the moon that I gave my teacher interns who were placed in small cooperative groups to arrange in chronological order over a month. The numbering of the photographs allowed me to display in a group chart the ways the different cooperative groups conceptualized the phasing of the moon over a month. By examining the chart for patterns, we quickly could detect similarities and differences in how the groups arranged the pictures (especially if they ranged from waxing to waning or waning to waxing). This simple act of quantifying events in the natural environment illustrated powerfully how the use of mathematics in science teaching/learning contexts can enable the detection of patterns, a mathematical concern shared by science. Pedagogically, this procedure enabled me to demonstrate convincingly to my interns that learners oftentimes bring differing views of scientific concepts to the science classroom. Taking my lead as model, I observed that my students started to plan for and enact connections between mathematics and science themselves in their lesson planning and in the other related course activities.

From the analysis of the teacher intern interview data, I learned that a one-course concerted attempt to make connections between science and mathematics can result in both positive and unanticipated outcomes. I also learned that teacher interns who come to science methods with prior experience in learning science in a connected manner with mathematics are apparently better able to conceptualize the innovation. I am troubled that interns may think of the discipline of mathematics as only a tool in science learning contexts. As result, I am left with the conviction that this form of innovation requires a high commitment by the science methods instructor, an extensive level of planning, and a heightened sense of awareness that interns may reinforce or construct undesired conceptions of mathematics as a discipline in science learning contexts. I concur with my coresearchers who are experts in mathematics education that it is problematic if interns perceive that mathematics is simply a tool in connected mathematics and science. Therefore, while recommending continued explorations in the innovation to make connections in teacher preparation between science and mathematics, my fellow researchers and I offer a cautionary tale for science teacher educators interested in this type of pedagogical innovation.

Epilogue Two: The MCTP Interns' Reactions

Due to the participation of five of the seven MCTP teacher interns in a subsequent study that examined their first two years of teaching (McGinnis, Parker, & Graeber, 2004), respondent reaction was delayed. The concern was that by reading the report, their actions as new teachers might be impacted, since they would be aware of the extent of the researchers' bias. Upon completion of the two-year, in-depth study of their teaching, this report was mailed for comment to those five MCTP participants.

All five participants responded and commented on how rich in detail they found the report. Mary, an elementary teacher, described it in this manner: "I thank you for depicting me the way I would have liked. I still feel proud of my background and preparation in the MCTP" (e-mail communication). Susan, an elementary teacher, thought the study was "great." She expressed that she benefited from reading the other study participants' comments. She also expressed that while she continued as a new teacher to support the pedagogical innovation of making connections between mathematics and science, that "with the extreme amounts of pressure we are under with state-wide test scores, there is less time to make these connections" (e-mail communication). Laura, an elementary teacher, stated that the study underscored to her what "a special bunch of teachers we are. I guess when we were all clumped together [MCTP and non-MCTP teacher interns in the science methods course], I did not recognize our uniqueness" (e-mail communication). Katie, a middle level mathematics and science teacher, concurred with Mary on the impact of the science methods course (and the MCTP program in general) by stating, "I agree that I am better prepared to make seamless connections between math and science." Furthermore, from her position as a teacher with two years of experience, she concurred that " . . . the connections made are often about the processes involved (exploration, investigation, problem solving, etc.). Science and math are not separate subjects—together they can teach you a way of thinking which is both creative and organized" (e-mail communication with McGinnis).

From Mark's standpoint, reading the manuscript prompted him to reflect on the complexity, and shortcomings, of attempting to make connections between mathematics and science in the middle level classroom. As he stated, . . .

> The connections made between mathematics and science in the [science methods] course seemed so natural. I didn't think of any shortcomings made by the professor while I was a student. However, I was struck by your conclusion that science methods instructors should be cautious in attempting to make connections and that it does take a large knowledge base based on research. I now think from my experience as a classroom teacher that this is true also. By that, I mean it takes so much more time and energy to prepare for an integrated lesson in the real school environment in which curricula are generally separate between mathematics and science. I have found from my own teaching experience that connections between mathematics and science are far easier for my students to understand in the processes rather than as concepts, disciplines. I mean, if the students don't see the connections in the disciplines (a very abstract outcome which rarely happens) in the limited time we have for the lessons, we have to move on, and that is a problem, a waste of time and energy for them and us. (telephone conversation)

Continuing Research

Ongoing research in this topic area is being conducted by McGinnis and associates. It is being supported by additional funding from the National Science Foundation (Project Nexus, a project in the Teacher Professional Continuum Program). Informed directly by the findings and insights as explicated in this present report, a new model of upper elementary/middle level science teacher preparation is being tested that incorporates connections among the sciences and mathematics throughout (including in transformative science content courses, science methods courses, and intern field-based placements in professional development schools and in informal afterschool science internships). The recommended standards-based instructional strategy selected to achieve this goal is a focus on data management and analysis. The teacher preparation programs under study include a Historically Black College/University (HBCU) and a Primarily White College/University (PWCU). Readers interested in learning more about Project Nexus are invited to visit www.projectnexus.umd.edu.

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Appendix

End-of-Semester Intern Interview

1. How would you define best practices in teaching science to upper elementary/middle level students? Probe: What strategies/methods/approaches?
2. This semester, what attempts at best practices did you see your science methods professor modeling in science methods?
3. In your science methods class, to what extent did you see your science professor attempting to make connections to mathematics? Probe: Please give examples. Please consider both content and processes.
4. What is your understanding of the reasons given to make connections between mathematics and science? Probe: If you were to observe an attempt to make connections between mathematics and science, how would you evaluate it? What would you look for? Are there any times it is not appropriate to make connections?
5. Do you see a role for making connections between mathematics and science in your future teaching? Please give examples.

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