Elementary Preservice Teachers' Conceptions of Common Approaches to Teaching Science and Mathematics

by

Kimberly Nunes-Bufford

A dissertation submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
December 12, 2011

Approved by

Charles Eick, Chair, Associate Professor of Curriculum and Teaching
Sara Wolf, Associate Professor of Educational Foundations, Leadership and Technology
Deborah Morowski, Assistant Professor of Curriculum and Teaching

Abstract

This study investigated preservice teachers' thinking about common approaches to math and science education for elementary children in grades K-6. Specifically, this study focused on preservice teachers' thinking on the interpretation of tools for conceptual development, consideration of processes for meaningful learning, and conceptions of pedagogical approaches between mathematics and science. The study occurred while elementary preservice teachers where in a jointly enrolled science and mathematics methods classes and subsequent internship. The learning cycle was a common approach used in the methods courses and used by elementary preservice teachers in the field. The nature of the students' understandings was examined through several data sources: open-ended pre and post-course tests and weekly blogs. Results indicated varied conceptions of tools, processes, and approaches in science and math teaching at the beginning of the methods courses. Many of the participants initially thought of science and math as being approached in differing ways. Initial views of science ranged from preservice teachers thinking of science in terms of teaching out of the textbook, watching videos, or conducting experiments. Initial views of mathematics teaching ranged from teachers demonstrating and students practicing, teaching real-world mathematics, or teaching mathematics with hands-on learning. All of the participants expressed broadened ideas about teaching mathematics and science at the end of both methods courses. At the end of the semester 82 percent of preservice teachers recognized commonalities in teaching approaches for math and science, including use of inquiry-based teaching, as well as the use of the learning cycle. Follow-

up observations were conducted from a portion of the participants during their student teaching experience. Case studies were presented of two of the preservice teachers' conceptions of use of tools, processes, and approaches to mathematics while in their internship. Jane wanted students to understand mathematics beyond memorizing formulas. With some mentoring, Jane developed and implemented lessons that used tools for conceptual development, processes for reasoning, and a learning cycle approach. Kate believed that mathematics needed to be approached with real life mathematics, such as time and money, in order to keep students engaged. With mentoring, Kate also implemented a few lessons following standards based math curricula that involved tools to promote understanding and processes for reasoning. However, by the end of the observation time she reverted back to a style of teaching that focused on learning facts in isolation.

Acknowledgements

First and foremost, thank you to my Heavenly Father. I am grateful to my family for all of their support as I traveled on this academic journey. I could not have done this without the love and support from my husband. Many thanks for all of the support and encouragement from the faculty and staff in the College of Education. Special thanks to Dr. Charles Eick for all of the guidance during this process. Special thanks to the preservice teachers for letting me be a part of their learning process.

Table of Contents

List of Tables

CHAPTER 1: INTRODUCTION

Overview and Rationale of Study

The purpose of this study was to investigate how preservice elementary teachers relate, understand, and use the common or shared teaching practices for effective mathematics and science learning. The study examined preservice teachers' concepts of the learning cycle, a teaching approach for mathematics and science with embedded processes and tools for conceptual understanding. The study took place with a class of preservice teachers (N=22) who were in their science and mathematics methods courses and subsequent student teaching. Conceptions of pedagogy, tools for conceptual development, and processes for meaningful learning were examined for mathematics and science teaching during the science and mathematics methods courses from a constructivist grounded theory perspective. A small number of participants (N=2) were observed as case studies during their full-time student teaching in order to ascertain if preservice teachers continued to use common approaches in mathematics teaching. During student teaching, the learning cycle approach, conceptions of pedagogy, tools for conceptual development, and processes for meaningful learning were examined for mathematics teaching from a qualitative case study perspective.

Solving problems with unknown solutions and the thinking processes involved in such tasks were foundational principles of the science and mathematics standards (National Council for Teachers of Mathematics (NCTM), 2000; National Research Council (NRC), 1996). Additionally, Partnership for 21st Century Skills (2006) identified problem solving and critical thinking as minimal skills required by employers of their employees in the workplace. In order to produce a work force with problem solving and critical thinking skills, teacher preparation programs needed to promote problem solving and critical thinking across the disciplines. Fostering interdisciplinary approaches in science and mathematics in preservice teacher education programs supported the development of common pedagogical approaches that focused on inquiry and problem solving, as found in the national science education and mathematics education standards (NCTM, 2000; NRC, 1996).

Brief Literature Review

National Standards

National standards came about in response to criticisms made about the state of education in America (Wong, Guthrie, & Harris, 2003). National standards in science and mathematics for students in the K-12 setting have been a focus of the National Council for Teachers of Mathematics (NCTM) (1989, 2000), National Research Council (NRC) (1996), and the Partnership for 21st Century Skills (Partnership for 21st Century Skills, 2009). Similarly, standards have been developed for teacher preparation programs in science (National Science Teachers Association (NSTA), 2003) and mathematics (Conference Board of the Mathematical Sciences (CBMS), 2001; Senk, Keller, & Ferrini-Mundy, 2000). Interstate New Teacher Assessment and Support Consortium (INTASC) (n.d.) developed general standards for new teacher candidates as well. All of the documents called for teachers to be able to design, implement, and integrate teaching that makes content meaningful through inquiry and problem solving processes. This shift from teaching that focuses on a transmission model of teaching was known as reform-based education movement.

The reforms in science and mathematics education recognized the richness and complexities of the subjects that can not be conveyed by teachers or learned by students in a teaching environment that focuses on skills in isolation (Akerson & Donnelly, 2008; Molina, Hull, Schielack, & Education, 1997). In order for students to develop an understanding of science and mathematics, conceptual understanding must be the goal for the subjects (Molina et al., 1997). Best practices for reform-based classrooms designed instruction to allow students to generate their own questions and seek answers, use tools to investigate concepts, and use processes to reason, conjecture, and demonstrate proof of their conclusions (Beeth, Hennesey, & Zeitsman, 1996; NCTM, 2000; NRC, 1996; Williams & Baxter, 1996). Posing problems with unknown solutions became a means to support exploration of ideas, helps students make connections, supports communication among students and teacher, and expand students' new knowledge to other areas (NCTM, 2000; NRC, 1996). In mathematics when students were working on a problem to determine the relationship between area of squares and area of triangles, they worked with tools, such as geoboards, to explore the concept. This exploration often created a discussion among students of their findings. Students may have used their geoboards to demonstrate why the area of a triangle is half of the area of a square and use the geoboard to support their claims. Similarly in science, students may have wondered about the role of earthworms in nature. After studying the earthworms in their natural habitat, they created miniecosystems in small groups to study the earthworms. The students within the small groups communicated, recorded their observations, and then presented their findings to the class based on the data they collected. In both cases, the lessons were designed to foster and promote finding out about the unknown. Elementary preservice teachers learned to development and implement such lessons as a part of their science and mathematics methods courses.

Mathematics education has been considered a critical needs area. Teachers have been charged with the task of teaching students beyond basic computations, but to complete complex mathematical tasks as well (U.S. Department of Education, 2011). In order to improve student achievement in mathematics, the quality of teaching needed to be improved (U.S. Department of Education, 2011). The use of the learning cycle in a mathematics methods course for elementary preservice teachers offered a unique way to help beginning teachers develop the skills necessary for quality teaching. Furthermore, it provided a framework for teaching mathematics that focused the mathematics on higher order thinking skills in a practical hands-on method of instruction.

Science Framework for Mathematics Teaching

Reformed based science classrooms involved students in concept development prior to learning definitions or algorithms (Marek & Cavallo, 1997). This is distinctly different from traditional classrooms, which were typically characterized by the teacher giving information and the students completing practice on the concept (Marek & Cavallo, 1997). In science, this type of traditional instruction may have included an experiment or demonstration to support the content provided by the teacher (Marek & Cavallo, 1997). However, proponents of concept development prior to explanation for science teaching have been around since the 1960s, prior to the national science standards (Atkin & Karplus, 1962; Bybee, 1997). Atkin and Karplus (1962) recognized that children entered schools with preexisting understandings and interpretations of the world around them, and teachers must provide additional experiences to help students connect their prior knowledge with the new knowledge. Engaging students in experiences helped them make connections to their existing understandings, developed questions for further study, and expanded the understanding of concepts in deeper ways. Atkin and Karplus (1962) concluded that students should explore concepts, define and develop the concept from the experience, and apply the newly learned concept to a new situation.

This model of exploration, concept development, and concept application has become the framework for science teaching and has been modified and expanded since the 1960s (Bybee, 1997). It often was referred to as the learning cycle since it mimics the way people naturally learn (Lawson, Abraham, & Renner, 1989; Schmidt, 2008). People began with consciousness of a new idea, then investigation of the new idea, and finally use of the new idea (Schmidt, 2008). As part of a learning cycle, inquiry-based teaching involved exploration around a central idea, formulation of questions, investigations to answer the questions, and reflection of learned ideas (Bell, 2001; Morrison, 2008; Tracy, 1999). Inquiry, therefore, was embedded within the learning cycle (Gee, Boberg, & Gabel 1996; Tracy, 1999; Withee & Lindell, 2006).

Although science education has included the learning cycle for several decades, the inform-verify-practice method of instruction still persists (Marek & Cavallo, 1997). Yet even within the inform-verify-practice model, students in science worked with materials and conducted cook-book experiments (Marek & Cavallo, 1997). The same could not be said in mathematics education. National standards called for a focus on mathematics for conceptual understanding rather than skill and drill (NCTM, 2000). However, the expository mode of teaching in mathematics still prevailed (Taylor, 2009). Within this system students learned isolated math skills and then practiced those math skills (Alsup, 2003). Learning skills in isolation and without context inhibited students making connections within mathematics and to other areas (U.S. Department of Education, 2011).

Conceptual understanding, as promoted in the science and mathematics standards, often was not the school experience of elementary preservice teachers (CBMS, 2001). Teacher candidates were often products of a traditional science and mathematics classroom where the teacher delivered the knowledge (Taylor, 2009). This pattern in the traditional mathematics classroom somewhat mirrored the traditional science classroom. In both cases students were being informed of concepts rather than learning concepts for themselves through a scaffolded approach (Marek & Cavallo, 1997). Approaching teacher candidate preparation from a perspective of inquiry and problem solving processes aligned the program with teacher preparation standards for science and mathematics teaching. The learning cycle in mathematics offered a framework in which students can explore mathematic concepts, investigate new ideas, and apply new ideas to other situations (Marek & Cavallo, 1997).

The Learning Cycle in Teacher Preparation

Elementary preservice teachers entered the undergraduate program with beliefs about science and mathematics that have been shaped by their mathematics and science experiences (Manouchehri, 1997). They often found mathematics dull and uninteresting (Jong & Brinkman, 1999) and filled with procedures to follow (Manouchehri, 1999). Elementary preservice teachers took methods courses prior to student teaching with the purpose to "help students discard some knowledge, beliefs, and dispositions about mathematics and pedagogy they bring to the preservice program" (Manouchehri, 1999, p. 199). The preservice methods course typically focused on the pedagogy for the applicable subject area (Manouchehri, 1999). The use of the learning cycle in both the mathematics and science methods courses was one way for preservice elementary teachers to experience science and mathematics through exploration, concept development, and extension of ideas (Cathcart, Pothier, Vance, & Bezuk, 2006; Marek, 2008; Reys, Lindquist, Lambdin, Suydam, & Smith, 2003). The learning cycle also offered a way of incorporating similar teaching methods found in science and mathematics in using tools for conceptual development (Chick, 2007; Fuller, 1996; Hill, 1997; Marek & Cavallo, 1997), discourse (Akerson, 2005; Heywood, 2007; Williams & Baxter, 1996), assessing student knowledge (Manouchehri, 1997; Marek & Cavallo, 1997; NCTM, 2000; NRC, 1996) inquiry-based teaching (Morrison, 2008; Manouchehri, 1997; Marek & Cavallo, 1997; NRC, 1996; Weld & Funk, 2005), and reflection (Bleicher, 2006; Hill, 1997; Manouchehri, 1997). Using the learning cycle in the science methods course and continuing it into the mathematics methods course offered a means of bridging and connecting standards-based approaches and would potentially help preservice teachers to be more effective science and mathematics teachers with the use of an inquiry-embedded approach for both subjects.

Although the learning cycle, as an inquiry embedded approach, had its roots in the science field (Bybee, 1997; Atkin & Karplus, 1962; Marek & Cavallo, 1997), the tenets align closely with the national mathematics standards. The mathematics standards promoted students working together (NCTM, 2000), as recommended in the exploration and elaboration phases (Bybee, 1997). Using concrete tools and solving problems to develop a deep understanding of the concepts was core to the mathematics standards (NCTM, 2000) and aligned with the exploration, explanation, and elaboration phases of the learning cycle (Bybee, 1997). According to the mathematics standards, students generated their own mathematical questions (NCTM, 2000), a part of the engagement phase (Bybee, 1997), and students generated conclusions (NCTM, 2000), a part of the explanation phase (Bybee, 1997). The exploration, explanation, and elaboration phases supported a focus on thinking and reasoning skills that leads to conjectures or arguments about the mathematics being examined (Bybee, 1997; NCTM, 2000).

The research that exists on preservice teachers and the learning cycle focused primarily on science (Lindgren & Bleicher, 2005; Marek & Cavallo, 1997; Marek, Maier, & McCann, 2008; Urey & Calik, 2008). Researchers have concluded that K-12 students using the learning cycle performed better on content questions than students in a traditional science classroom (Cardak, Dikmenli, & Saritas, 2008; Ergin, Kanli, & Unsal, 2008; Ören & Tezcan, 2009; Soomor, Qaisrani, Rawat & Mughal, 2010). Similarly, direct teaching of the learning cycle approach positively influenced elementary preservice teacher's efficacy of teaching science using the learning cycle (Settlage, 2000). Hanuscin and Lee (2008) used the learning cycle as an effective approach with their elementary preservice teachers during the science methods course. They found the learning cycle was an effective approach with elementary preservice teachers. After experiencing science with the learning cycle, the preservice teachers successfully developed a sequence of activities to use with students following the learning cycle approach. The results from learning cycle assessments indicated that elementary preservice teachers had greater understanding of some aspects of the learning cycle, but that their conceptions of implementation of the learning cycle did not always follow its intended use (Hampton, Odom, & Settlage, 1995; Marek, Laubach, & Pedersen, 2003). Gee et al. (1996) similarly noticed preservice teachers implemented the learning cycle in their field placements but left out the extend phase. Understanding of the learning cycle improved with the continued exposure of the learning cycle in methods class, but some had a difficult time conceptually changing their ideas about teaching science (Hanuscin & Lee, 2008; Lindgren & Bleicher, 2008).

In addition to examining preservice teachers understanding of the learning cycle, researchers noticed the acceptance of teaching science with the learning cycle approach. Gee et al. (1996) were disappointed to find that preservice teachers were not fully committed to the learning cycle as an approach for science. They believed that it was difficult for the preservice teachers to accept a different way to approach teaching science. Lindgren and Bleicher (2008) drew similar conclusions when some of the strongest science students were reluctant to use the learning cycle as an approach for teaching science. However, students who had negative science experiences or were dissatisfied with the way they were taught, embraced the learning cycle approach.

There was a scarcity of research on the learning cycle in mathematics education. However, researchers teaching preservice teachers have provided examples of the learning cycle and mathematics in science lessons (Marek & Cavallo, 1997; Marek et al., 2008; Simon, 1992). Marek (2008) described a science lesson in which students measured the circumference of objects to make a conclusion about the relationship of the circumference and diameter of circles. His description illustrated how the learning cycle could be used in mathematics teaching. Although his example was for a science lesson, it very easily could have been for a mathematics lesson on understanding the area of circles. Similarly, Marek and Cavallo (1997) explained that the learning cycle could be used in mathematics for problem solving and provided examples of learning cycle lessons to teach measurement and geometry concepts. Simon (1992) recognized the use of the learning cycle in mathematics methods courses. He described a mathematics methods class in which teacher candidates solved a problem situation, discussed solutions, and extended new ideas into other problem situations.

Research Questions

Preservice teachers in this study were in science and mathematics methods classes which were taught with the learning cycle approach. Research needed to be conducted to analyze the bridge between mathematics and science methods courses and student teaching experiences in mathematics for elementary preservice teachers (Jong & Brinkman, 1999). In order to ascertain how preservice teachers carried over the learning cycle approach into their mathematics teaching, preservice teachers needed to be studied as they moved through the teacher preparation process. Although numerous studies existed on various levels of content knowledge (Ball, 1988; Davis & Petish, 2005; Hill, 1997; McLeod & Huinker, 2007; Rice, 2005; Summers, Kruger, & Childs, 2001; Turnuklu & Yesildere, 2007), beliefs (Ball, 1996; Fuller, 1996; Manouchehri, 1997), and other factors (Chick, 2007; Even, Tirosh, & Markovits, 1996; Manouchehri, 1997) influencing preservice teachers within elementary education programs, very little data existed on the study of elementary preservice teachers in relation to their understanding of the learning cycle and subsequent commonalities in practice between mathematics and science teaching (Offer & Mireles, 2009; Stinson, Harkness, Meyer, & Stallworth, 2009) as recommended by the National Research Council (1996), National Science Teachers Association (2003), and the Partnership for 21st Century Skills (2009).

This research offered an opportunity to examine preservice teachers dually enrolled in science and mathematics methods courses and as they moved from methods courses through student teaching. Furthermore, it provided insight into the ways in which elementary preservice teachers considered tools for conceptual development, processes for learning, and approaches for learning mathematics during a student teaching experience. In order to examine the response preservice teachers had with processes that occurred similarly in science and mathematics, the participants' science and mathematics methods courses were approached from a similar pedagogical perspective with use of the learning cycle. Preservice teachers then were expected to use the learning cycle approach in their laboratory teaching experiences. In order to determine if teacher candidates continued with the learning cycle approach in mathematics, a sub group of these participants were studied during their student teaching experience. The research questions for this study were: (1) What are preservice teachers' conceptions of tools for conceptual development, processes for meaningful learning, and pedagogical approaches to mathematics and science prior to and after taking the mathematics-science methods courses? (2) What changes, if any, in development of knowledge and understanding of the common approaches between mathematics and science occurred while taking the mathematics-science methods courses? (3) How did preservice teachers put into practice during student teaching their thinking from the methods courses on tools for conceptual development, processes for meaningful learning, and pedagogical approaches to mathematics teaching?

Participants, Research Methods, and Organization of this Dissertation

The research design was a qualitative study conducted in two phases. The study was conducted in two phases due to the nature of the teacher preparation process. During Phase I, students were participating in science and mathematics methods courses. The purpose of the methods courses was to provide preservice teachers with the opportunity to learn the pedagogy and put the pedagogy into practice on a small scale. During the methods courses, participants spent part of their time on campus and part of their time in field experiences. The second phase of the study occurred during the student teaching experience. The student teaching experience provided more time for the preservice teachers to develop as teachers and practice teaching. In the student teaching experience preservice teachers spent every day of the semester in a classroom gradually accepting all of the responsibilities of the classroom teacher. They were expected to take over all of the responsibilities for a two-week time period. During that time the student teacher was responsible for planning lessons, implementing, lessons, and the day-to-day business of a classroom. Conducting the study in two phases allowed for examination and delineation of growth of thinking and practice in mathematics teaching as preservice teachers progressed through the latter part of their program.

The first phase consisted of 22 elementary pre-service teachers who completed pre-tests, post-tests, and on-line blogs during their jointly enrolled mathematics and science methods courses. The differing modes of data collection were used to reveal preservice teachers' thoughts and knowledge of common science and mathematics practices as they developed throughout the methods courses. Phase II of the study consisted of studying two of the Phase I participants during their student teaching experience. Data sources for Phase II consisted of lesson plans, observations, follow-up interviews, and a final reflection on their mathematics teaching experiences. The two cases were selected for several reasons. First they were placed in a school that participated in science and mathematics reform initiatives and had resources for their mathematics teaching. Secondly, they both were given the freedom by their cooperating teachers to design and implement mathematics lessons as long as they taught the assigned objectives. Thirdly, the cases represented two perspectives on approaching mathematics teaching. The two cases were selected due to the richness of data they provided. The various types of data collected during student teaching were used to indicate how preservice teachers' thinking and practice changed as they moved along the teacher development continuum. Following Phase II data collection, the cases studies were examined for emerging themes and compared with themes from Phase I. Following data analysis of Phase I, the cases were examined for emerging themes within each case and across cases.

Overview of Results

Data collected during the methods portion of the study revealed varying conceptions of tools, processes, and approaches for science and mathematics teaching. Participants overall entered the methods courses with the perceptions of science and mathematics as being two separate subjects with two different methods of teaching. By the end of the semester, through the use of the learning cycle, most of preservice teachers recognized that science and mathematics could be approached similarly. Participants who held traditional views, in which the teacher disseminated the information and students practiced, initially were more likely to hold onto those beliefs. However, preservice teachers who entered the methods courses with more expanded notions of science and mathematics teaching broadened their understandings.

The two cases studied offered additional insight into the development of elementary preservice teachers. The cases presented two very different student teachers with similar and differing pedagogical issues. Teaching practices that were exhibited during the methods class were maintained during student teaching. In the case of Jane, she exhibited expanded notions of teaching science and mathematics through hands-on teaching during the methods course. During student teaching, after some guidance, she was able to implement hands-on lessons in mathematics, although not on the level of full inquiry. Kate, on the other hand, demonstrated more traditional views of science and limited views of mathematics in terms of real world mathematics. During her student teaching, in mathematics she taught investigation type lessons but under a great amount of teacher control which limited the richness of the learning for the students.

This dissertation consists of a review of the literature, a methodology section, two articles, and a final chapter. The first article focuses on the themes that emerged from the findings of the study conducted while pre-service teachers were jointly enrolled in mathematics and science methods courses. The second article consists of the themes from practice in mathematics that emerged from the two case studies during the student teaching. The final chapter of this dissertation examines the overall findings and conclusions.

CHAPTER 2: REVIEW OF LITERATURE

The review of literature focused on elementary preservice teachers and common pedagogical approaches to mathematics and science and is presented in the following sections:

Efforts to Reform Science and Mathematics Education

Since the launching of Sputnik in 1957 (Garber, 2007), cries for reform in science and mathematics education have been made throughout the educational arena (Bybee, 1997; Gates, 2005). The National Science Foundation (NSF), established in 1950, became the only federal agency to promote science and engineering research and education (NSF, 2009). With the establishment of NSF came the National Science Board (NSB), the people appointed by the president to provide input to the foundation (NSF, 2009). Beginning in 1954, a summer program was funded through the National Science Foundation to support the mathematical knowledge of teachers (NSF, 2009). Since that time NSF grants have continued to provide funding for research, education, and other programs directed towards the improvement of science and mathematics (NSF, 2009).

Despite the efforts of the National Science Foundation and the research efforts that have been funded as a direct effort of the agency, concerns with the state of mathematics and science education persisted (NSB, 2004). In examining the data on science and technology in the United States, the National Science Board (2004) concluded that the number of jobs requiring knowledge of science and engineering would increase without a prepared job force to fill those positions if things continue in the United State with science and mathematics. The National Science Board Report (2004) also indicated that fewer American school children and women were choosing science and engineering fields. Furthermore, the percentages of foreign born individuals in areas of science and engineering with graduate degrees increased over the last few years from 24 to 38 percent (NSB, 2004).

Concerns for the state of education persisted in the United States with other stakeholders, including interest groups, businesses (Gates, 2005), and parents (Kadlec & Friedman, 2007). The Public Agenda conducted a survey among students and parents to determine the level of satisfaction of science and mathematics education (Kadlec & Freidman, 2007). Of parents and students surveyed by Kadlec and Freidman (2007), both groups believed that America was behind other countries in mathematics and science, yet they were pleased with the mathematics and science education in the local schools. African American and Hispanic parents surveyed, however, indicated that their schools were below where they needed to be in the teaching of mathematics and science (Kadlec & Freidman, 2007). The disparity of satisfaction and complacency with American schools presented additional problems for a nation that was operating high schools as they did fifty years ago (Gates, 2005).

National Standards

Like the launching of Sputnik, the release of *A Nation at Risk* by the National Commission on Excellence in Education (1983) sparked renewed concerns with the education system of the United States (Wong, Guthrie, & Harris, 2003). Recommendations by the eighteen member commission included increasing high school graduation requirements, raising standards and expectations for four year colleges, increasing the time students spent in school, improving the preparation of teachers, and expecting the public to hold the system accountable for making these improvements (National Commission on Excellence in Education, 1983). At the national level, standards were developed as a means of improving and reforming the American educational system to improve student achievement (Wong et al., 2003).

Those standards for science and mathematics came about from the efforts of the National Research Council (1989, 1996) and the National Council of Teachers of Mathematics (1989, 1991, 2000). Science standards documents included the *National Science Education Standards* (NSES) (National Research Council, 1996) and *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993). Mathematics standards began with *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989), *Assessment Standards for School Mathematics* (NCTM, 1995), and *Professional Standards for Teaching Mathematics* (NCTM, 1991). From the preceding documents, the areas of curriculum, assessment and professional standards were updated and combined in *Principles and Standards for School Mathematics* (NCTM, 2000). More recently NCTM published *Curriculum Focal Points for Prekindergarten through Grade 8 Mathematics: A Quest for Coherence* (2006) and *Focus in High School Mathematics: Reasoning and Sense Making* (2009). These documents focused on more specific grade level standards for pupils. The National Research Council (2001) published *Adding it Up*, a report that described proficiency in mathematics as conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. Most recently the Common Core State Standards Initiative (2010), headed by the National Governors Association and Council for Chief State School Officers, developed standards for language arts and mathematics that focused on reasoning, critical thinking, and problem solving for all states to adopt.

Standards have been developed for teachers and teacher preparation programs as well. Interstate Teacher Assessment and Support Consortium (INTASC) (n.d.) developed general standards for new teacher candidates. The standards included development, planning, and implementation of lessons that incorporate a variety of strategies, meeting the needs of diverse learners, and working within the school community. The Conference Board of the Mathematical Sciences (2001), in *The Mathematical Education of Teachers*, focused their standards and recommendations on what teachers and teacher preparation programs needed to have in order to promote successful mathematics programs. They described the challenges elementary teacher programs have in the preparation of teachers in teaching mathematics. They also recommended that preparation programs work with mathematics faculty to design content courses that provides a deep examination of mathematics.

Similarly, the National Science Teachers Association (2003) developed *Standards for Science Teacher Preparation*. The *Standards for Science Teacher Preparation* (NSTA, 2003) described the content knowledge elementary and secondary teachers need in their preparation program, including earth, space, and life science. Accredited teacher preparation institutions follow standards to maintain the accreditation of their programs. The Association for Childhood Education International (ACEI) in association with the National Council for Accreditation of Teacher Education (NCATE) developed standards for teacher preparation institutions to receive accreditation of their programs (ACEI, 2007).The resulting documents called for teacher candidates to be able to design, implement, and integrate teaching that makes content meaningful through inquiry and problem solving processes.

Reform Movement

Despite the efforts of the NCTM and NRC over the last two decades, preservice teachers were often products of a traditional science and mathematics classroom where the teacher delivers the knowledge (Taylor, 2009). In the science classroom this traditional approach was known as inform-verify-practice (Marek & Cavallo, 1997). With this approach the teacher informed the student about a science concept, the student verified the concept, and then completed additional practice problems (Marek & Cavallo, 1997). Sometimes these verification activities were called experiments (Marek & Cavallo, 1997). However, they were not true experiments because the students already knew what to expect (Marek & Cavallo, 1997). Furthermore, since students were informed and told the information, they weren't involved in true science learning (Marek & Cavallo, 1997). The traditional mathematics classroom often began with the teacher introducing the new material, students worked on problems often algorithmic in nature, and the teacher answered questions (Alsup, 2003).

However, the inform-verify-practice approach for traditional science classrooms and the tell-practice approach of traditional mathematics classrooms did not take into account the richness and complexities of these two fields. A complex framework of generalizations, ideas, and relationships composed the nature of mathematics (Molina et al., 1997) and the nature of science (NOS) (Akerson & Donnelly, 2008). The recognition of this complex framework created a different schema for the teaching and learning of these two fields. In order to develop the skills to make generalizations, to understand ideas, and to examine relationships, conceptual learning must be developed (Molina et al., 1997). The shift in thinking about the nature of teaching mathematics and science created a change in curriculum (NCTM, 1989, 1991, 2000; NRC, 1989. 1996) from the teaching of isolated skills to a development of skills in context (Molina et al., 1997) and became known as the reform movement (Williams & Baxter, 1996). Constructivist philosophy has influenced educational efforts greatly since the 1980s when the reform movement began (Vernette, Foote, Bird, Mesibov, Harris-Ewing, & Battaglia, 2001). Within the standards documents constructivist philosophies could be seen as the teaching and learning process is described as active involvement to develop understanding for each student (NCTM, 2000; NRC, 1996).

Reforms in science and mathematics education were characterized with a move away from lower order thinking skills to higher order thinking skills (Tal, Dori, Keiny, & Zoller, 2001). In a reformed mathematics classroom it was accepted that students generate their own mathematical conclusions and questions (Beeth, Hennesey, & Zeitsman, 1996; NCTM, 2000; Williams & Baxter, 1996). A reformed science classroom indicated a shift from learning isolated science information to a development of understanding about science phenomena and the nature of science (Beyer & Davis, 2008). Both science and mathematics reformed classrooms were characterized by a focus on thinking and reasoning skills that leads to conjectures, or arguments, about the science or mathematics being examined (NCTM, 2000; NRC, 1996; Williams & Baxter, 1996). Reform classrooms involved students working together, using concrete tools, and solving problems to develop a deep understanding of the concepts (Williams & Baxter, 1996).

Integral to the enactment of the reform movement were teacher education programs (Manouchehri, 1997; McGinnis, Kramer, & Watanabe, 1998). Teacher education programs provided the knowledge base for future teachers that include content and pedagogy (Manouchehri, 1997). Teachers in reform classrooms acted as a facilitator, helping guide students to mathematical or science conceptual understanding, rather than serving as the giver of knowledge (Beyer & Davis, 2008; Williams & Baxter, 1996). Teacher education programs have to establish a process that provided preservice teachers the opportunities to develop those skills as facilitators in context (Manouchehri, 1997; Noori, 1994; Speilman & Lloyd, 2004).

Curriculum

The reform movement also impacted the development of curricular materials different from traditional textbooks (Klein, 2003). Battista (1999) noted that the traditional textbook curriculum developers were not fully apprised of research on student learning, and concluded that “sound curricula must include clear long-range goals for ensuring that students become fluent in employing those abstract concepts and mathematical perspective that our culture has found most useful” (p. 424). Li and Fuson (2002) identified two concerns of existing curricular materials including how the materials aid in student achievement and the embedded ideas in the presentation of material. Educators have to be mindful of how concepts are presented in curricular materials and how they use such materials in teaching (Renner, Abraham, Grzybowski, & Marek, 1990).

Curricular materials were often in the form of textbooks, and textbooks played a role in the teaching and learning in the classroom (Stamp & O’Brien, 2005). Traditional textbooks in science and mathematics often included a large number of concepts that focus on examples and definitions of concepts (Stamp & O’Brien, 2005). De Villiers (2004) argued that “just knowing the definition of a concept does not at all guarantee understanding of the concept” (p. 708). Just because students could recite the definition of a rectangle doesn’t mean that the students could recognize that a square is a specialized rectangle. Furthermore, Cannizzaro and Menghini (2006) felt that definitions needed to arise from students’ experiences with concepts. From their research with students and textbook problems, Renner et al. (1990) concluded that science teachers that focus on the textbook create a classroom in which students are not experiencing science but rather just reading about science.

Reform-based curricular materials differed from traditional textbooks (Lloyd & Frykholm, 2000). Reform curricula emphasized problem solving tasks, real world applications, and exploration of topics (Goodnough & Nolan, 2008; Lloyd & Frykholm, 2000). Reform-based materials focused on students making sense of the concepts rather than isolation of facts. “In sense-making curricula, on the other hand, because students retain learned ideas for long periods of time, and because a natural part of sense-making is to interrelate ideas, students accumulate an ever-increasing store of well-integrated knowledge” (Battista, 1999, p. 432). Reform curricula often included examples of student thinking, information about the concept, discussion questions, and various means of assessing student learning (Lloyd & Frykhom, 2000).

All of these factors influenced the enacted curriculum in the classroom. The enacted curriculum was the curriculum the teacher actually teaches. For traditional science classrooms this often entailed reading of texts, vocabulary lists, worksheets, and lecture (Weiss, 1994). Renner et al. (1990) found that when teachers followed textbooks that their role was then to support the textbook content. Furthermore, as students moved from primary to intermediate grades the number of hands-on activities in science often diminishes (Fulp, 2002). Similarly, a traditional mathematics classroom often encompassed learning specific skills in isolation and the practice of those skills (Alsup, 2003).

However, curricular materials alone did not ensure a reform based classroom (Battista, 1999; Huang, 2000). Battista (1999) found that even with reform based materials that teachers potentially could distort the ideas in the materials if the teacher had misconceptions about the content. The variety of responses from students when given the same curriculum “…provides evidence of the interplay between curriculum as designed and curriculum as ‘wrapped’ around the ongoing action and interaction of students and teacher” (Cannizzaro and Menghini, p. 376, 2006). Similarly, Huang (2000) expressed concerns for teachers who followed curricula materials closely without taking into account the learning needs of the students.

Knowledge

Content Knowledge

There are different types of knowledge needed by teachers (Stotsky, 2006). Shulman (1986) identified three types of knowledge needed by teachers: content knowledge, pedagogical content knowledge, and curricular knowledge. Content knowledge of teachers, sometimes referred to as subject matter knowledge, involved the actual content that teachers themselves know (Ball, 1996; Manouchehri, 1997). Fact, concepts, and principles of a subject comprised content knowledge (Manouchehri, 1997). Knowledge of facts was also known as declarative knowledge (Jacobs & Paris, 1987). Knowledge of processes was called procedural knowledge (Jacobs & Paris, 1987). Content knowledge included both common knowledge and specialized knowledge (McLeod & Huinker, 2007).

Elementary teachers were expected to have sufficient content knowledge (McLeod & Huinker, 2007; Shulman, 1986). Elementary teachers also were expected to have content knowledge of all subjects including, but not limited to, language arts, social studies, science, and mathematics (Davis & Petish, 2005). Content knowledge of mathematics included knowledge of numbers and operations, algebra, data and statistics, and geometry (NCTM, 2000). Content knowledge of science included life science, physical science, space science, and earth science (Davis & Petish, 2005). Stotsky (2003) argued that “a deep knowledge of the academic content supporting the field of teacher’s license is the sine qua non for defining teacher quality” (p. 257). In examining the knowledge of environmental science content with preservice teachers and in-service teachers, data indicated some misconceptions in in-service teachers but greater misconceptions in preservice teachers (Summers et al., 2001). Teachers can not teach effectively what they do not understand themselves (Ball, 1996; Summers et al., 2001).

Teachers were expected to not only know the what of mathematics and science knowledge and the why for teaching the mathematics and science (Even et al., 1996; Kelly 2000). Teachers also were expected to know common algorithms and science facts, examples of common content knowledge (McLeod & Huinker, 2007). Knowing why and when strategies should be applied is known as conditional knowledge (Jacobs & Paris, 1987). Teachers were also expected to know why algorithms work or why scientific tenets hold true (Even et al., 1996), an example of specialized content knowledge (McLeod & Huinker, 2007). Specialized content knowledge enabled teachers to examine students' solutions and students' misconceptions (Even et al., 1996). Teachers recognized their content knowledge as an influencing factor in their ability to teach a subject (Goodnough & Nolan, 2008). Knowledge about mathematics and science, including mathematics and science origins, history of mathematics and science, and how truths are determined, also comprised knowledge of mathematics and science (Ball, 1996; Justi & Gilbert, 2000; Kistler, 1997). Teachers expressed implicitly and explicitly the knowledge they have about a subject through the types of assigned tasks, ways unpredicted student responses are handled, and the role of curricular materials in the lessons (Ball, 1988).

Furthermore, content knowledge involved teachers not only knowing the content but having the ability to incorporate new knowledge into the previously learned knowledge (Anderson & Hoffmeister, 2007). The authors concluded that "…a definition of teachers' content knowledge should include not only the capacity to learn, but also the concomitant recognition that learning involves attention to connections and concepts" (p. 201). Furthermore, it was not just content knowledge that was important, but it was also important how teachers learned the content (Jones, 2000). If teachers learned content for facts, then their knowledge base was limited to facts. If teachers learned concepts and the relationships to other concepts, then their knowledge base was deeper. Zull (2002) determined that understanding the prior knowledge and experiences of the students was critical for teachers to build new knowledge. Teacher knowledge affected the decisions of the day-to-day classroom from the interpretation of the materials, the presentation of materials, and interaction with the students (Paton, Fry, & Klages, 2008; Shulman, 1986). Teacher knowledge was important for interpreting students' unpredicted mathematics and science responses (Ball, 1996; Summers et al., 2001)

If teachers were expected to be effective, they must have an understanding of the concepts, rules, and principles of the content (Beeth et al., 1996; Manouchehri, 1997). They were expected to be able to explain and interrelate the concepts to students (Ball, 1996; Even et al., 1996; NCTM, 2000; Shulman, 1986). Skemp (1976) described knowing the what and the why of mathematics as relational understanding. An instrumental view was a view of mathematics as a set of memorized formulas and rules (Skemp, 1976). Hill (1997) found that elementary preservice teachers initially held an instrumental view of mathematics. Similarly, Ball (1988) found that elementary preservice teachers had fragmented knowledge of mathematics and Rice (2005) found preservice teachers lacked an understanding of basic science concepts. This fragmented knowledge inhibited teachers in analyzing students' misconceptions and determining alternate means of teaching a concept (Rice, 2005).

In addition to knowledge of content, Hill et al. (2008) identified specialized knowledge of mathematics as mathematical knowledge of teaching (MKT). Mathematical knowledge of teaching was quite complex. It included a respect of mathematics and a level of content knowledge that was different from what a mathematician might need (Hill & Ball, 2009).

Furthermore, teachers were to be able to "unpack" ideas encompassed in mathematical concepts and to be able to understand mathematical justifications of the end result (Hill et al., 2008). For example, teachers may have memorized a rule for division of fractions to "flip and multiply" but this did not take into account "the mathematical knowledge to *teach* this topic" (Hill & Ball, 2009, p. 68). Finally, teachers with MKT knew where students were in their mathematical thinking and where the students should grow and develop in mathematical thinking (Hill et al., 2008).

Pedagogical Content Knowledge

Subject matter or content knowledge alone was not sufficient to be an effective teacher (Davis & Petish, 2005; Manouchehri, 1997; Turnuklu & Yesildere, 2007). Teachers needed knowledge of students and how to teach (Even et al., 1996; Heywood, 2007; Hovey, Hazelwood, & Svedkausite, 2005; NCTM, 2000; Turnuklu & Yesildere, 2007). Shulman (1986) named this type of knowledge as pedagogical content knowledge. This knowledge included teachers knowing the most useful representation of a concept, understanding interrelationships of concepts, and obstacles learners may have with the representations or interrelationships of concepts (Davis & Petish, 2005; Even et al., 1996; Heywood, 2007; Manouchehri, 1997; Summers et al., 2001). Daehler and Shinohara (2001) considered pedagogical content knowledge as knowledge of the level of difficulty of the concept, as well as knowledge of how to present the concept to make it understandable to students. Both knowledge of the content and knowledge of the best way to teach the content were necessary for effective teaching and learning and must take into account students' prior knowledge and experiences (Daehler & Shinohara, 2001; Davis & Petish, 2005; Manouchehri, 1997).

New teachers often exhibited limited pedagogical content knowledge (Davis & Petish, 2005; Manouchehri, 1997). For both science and mathematics this type of knowledge involved an in-depth understanding of the concept along with proficiency in being able to identify student thinking (Daehler & Shinohara, 2001; Davis & Petish, 2005; Heywood, 2007; NCTM, 2000). Once the teacher had identified and assessed where the students were conceptually, then the teacher created learning experiences that helped students build a depth of understanding based on the students' level of comprehension (Heywood, 2007). Turnuklu and Yesildere (2007) found that elementary preservice teachers did not have sufficient knowledge of assessment to develop and elicit understanding of student conceptions.

Pedagogical content knowledge also included decisions teachers make with regard to methods of teaching and knowledge about students' abilities (Davis & Petish, 2005; Even et al., 1996; Fuller, 1996). Teachers' content knowledge influenced pedagogical choices made by the teachers (Even et al., 1996). Pedagogical choices teachers made influence learning opportunities for students (Davis & Petish, 2005; Martin, McCrone, Bower, & Dindyal, 2005). In inquiry-based classrooms, teachers made pedagogical decisions between letting students arrive at their own conclusions and making sure students know science terminology (Harlow & Otero, 2006). Martin et al. (2005) found that "the teachers choice to pose open-ended tasks (tasks which are not limited to one specific solution or solution strategy), engage in dialogue that places responsibility for reasoning on the students, analyze student arguments, and coach students as they reason, creates an environment" (p.95) for students to actively participate in the proof and reasoning process. In addition to pedagogical choices made by teachers, the manner in which teachers dealt with unexpected responses and questions from students reflected the pedagogical knowledge of that teacher (Even et al., 1996; Fuller, 1996; Martin et. al, 2005).

Preservice teacher education programs needed to provide experiences that allowed preservice teachers to move from learning content to thinking about content and students in the teaching/learning environment (Even et al., 1996; Manouchehri, 1997). Preservice teachers needed knowledge of educational theory as well as knowledge of day-to-day decision making in the classroom (Manouchehri, 1997). New teachers were more concerned with their teaching performance, when they first begin to practice teach, than with student learning (Manouchehri, 1997). This transition from self to students was found to occur as the new teachers developed pedagogical reasoning defined as the ability to examine the pedagogical choice, recognize potential solutions, and devise a solution that best fits the learning situation (Davis & Petish, 2005; Manouchehri, 1997).

Curricular Knowledge

Shulman (1986) identified curricular knowledge as another type of knowledge needed by teachers. The manner in which teachers converted curricular materials into learning experiences demonstrated their curricular knowledge (Davis & Petish, 2005; Shulman, 1986). Furthermore, Shulman (1986) criticized teacher education programs for their lack of curricular knowledge preparation. Textbooks often were considered lacking by teachers in the presentation or approach of a topic (Shulman, 1986; Stamp & O'Brien, 2005). Not only did teachers need to be familiar with the curriculum they were expected to teach, but they also needed knowledge of alternative curriculum materials (Shulman, 1986; Stamp & O'Brien, 2005). Shulman (1986) identified that teachers with strong curricular knowledge were able to relate what students were learning in other classes as well. Shulman (1986) called this lateral curricular knowledge.

Teachers needed to be able to evaluate the appropriateness of the curricular materials, determine how to present or alter the information presented, and perhaps determine alternative curriculum materials (Davis & Petish, 2005; Fuller, 1996; Shulman, 1986). Curricular materials played a powerful role in the classroom (Renner et al., 1990; Spielman & Lloyd, 2004). Preservice teachers had a disadvantage when using curricular materials due to their lack of experience and may not interpret the materials appropriately (Davis & Petish, 2005).Teacher actions may have resulted from reactions to classroom events that occur spontaneously and not from carefully considered pedagogical choices (Martin et. al., 2005), or from other beliefs about the curriculum (Chick, 2007). A teacher whose goal was to make sure students write proofs similar to the textbook has different goals than a teacher who wanted to aid students to make sense of the proofs and the reasoning behind the mathematics. Davis and Petish (2005) recommended that teacher education programs should provide opportunities for preservice teachers to learn how to critically examine curricular materials.

Constructivist Perspective on Learning

Constructivism was found in the research and conceptions of learning based on the works of John Dewey (1933), Jean Piaget (1976), Lev Vygotsky (1962), Howard Gardner (1983), and Jerome Bruner (1968) (Beeth et al., 1996; Lever Duffy & McDonald, 2011; Vernette et al., 2001). Knowledge occurred at two levels, with the first level as the actual experience (Beeth et al., 1996; Zull, 2002). At the second level was how the person categorized the experience with other experiences (Beeth et al., 1996; Zull, 2002). The constructivist perspective recognized that learning is unique for each person and is based on each person's experiences (Beeth et al., 1996; Lever-Duffy & McDonald, 2011; Marek & Cavallo, 1997). Therefore, teachers with a constructivist philosophy viewed learning as a unique experience for each student as each student is unique (Beeth et al., 1996).

The manner in which a teacher teaches based on a constructivist philosophy was called constructivist pedagogy (Beeth et al., 1996). A constructivist classroom was characterized as a move away from a transmission model of teaching (Jaeger & Lauritzen, 1992; Vernette et al., 2001). Active learning was a key component in a constructivist classroom which encompasses students making connections, scaffolding of learning, options in learning, learning for understanding of concepts, using a variety of assessment methods, inquiry, and a student centered environment (Vernette et al., 2001). Social interaction was a key element of social constructivism involving negotiation of meaning with classroom peers to foster learning (Kim & Darling, 2009). This negotiation and meaning making was different from a traditional teacher centered classroom. Ka-Ming and Kit-Tai (2006) found the students learning in a constructivist classroom, in comparison to students in a teacher-centered classroom, had deeper understanding of the material.

In addition to content knowledge, curricular knowledge, and pedagogical content knowledge, teachers needed to have the ability to foster knowledge development, reflection, and communication of learning (Beeth et al., 1996). Since constructivist philosophy placed more demands cognitively on students to go beyond regurgitation of facts, teachers had to be able to assess student cognition (Beeth et al., 1996). Furthermore, processes must be facilitated by the teacher in order for students to "make meaning of their world by logically linking pieces of their knowledge, communication and experiences" (Jaeger & Lauritzen, 1992, p.1).

Processes for Meaningful Learning in Science and Mathematics

Processes for meaningful learning were based on the processes as described in the *Principles and Standards for School Mathematics* (NCTM, 2000) and the *National Science Education Standards* (NRC, 1996). Process skills were also considered thinking skills (Sambs, 1991). These processes included problem solving, reasoning and proof, communication, connections, and representations (Goodnough & Nolan, 2008; Justi & van Driel, 2005; NCTM, 2000). In mathematics, students were asked to reason about their answers and demonstrate proof (NCTM, 2000). Similarly in science, students were expected to be able to validate findings and be able to evaluate the conclusions of others (NRC, 1996). In mathematics, students were expected to communicate their findings (NCTM, 2000). Likewise, in science students were expected to be able to explain their findings (NRC, 1996). In mathematics, students were expected to solve problems (NCTM, 2000). In science, students were expected to ask questions and then find the answers to those questions (NRC, 1996). In mathematics, students were expected to be able to represent their work (NCTM, 2000). In science, students were expected to present their scientific knowledge (NRC, 1996). In mathematics and science, students were expected to make connections or identify relationships between and among concepts and areas of study (NCTM, 2000; NRC, 1996).

Manouchehri (1997) recommended that preservice teachers must "explore, analyze, construct models, collect and represent data, present arguments, and solve problems" in mathematics (para.11). Cady, Meier, and Lubinski (2006) found that when using practices aligned with NCTM recommendations in the methods course and in the field placement that those preservice teachers continued to implement problem solving, classroom discourse, and multiple forms of assessment. Likewise, Banchoff (2000) determined that, "given opportunities to act as mathematicians do and to share their thinking with classmates, students will develop the skills, habits, and dispositions of young mathematicians" (p. 350). After examining knowledge of preservice teachers, Akerson and Donnelly (2008) concluded that the National Science Education Standards (NRC, 1996) needed to be emphasized in teacher preparation programs in order to help preservice teachers more fully develop their understanding of the nature of science and how science works.

Problem Solving. Problem solving was one of the processes common to science and mathematics teaching. “Problem solving means engaging in a task for which the solution is not known in advance” (NCTM, 2000, p. 52). For science, the problem solving process often occurred during scientific inquiry in which students are finding out the unknown (NRC, 1996). Whether called problem solving, as in mathematics, or inquiry, as in science, students were expected to learn how to gather information, record collected data, and offer answers and explanations of those answers (NCTM, 2000; NRC, 1996). Since not all problems are simple, problem solving caused the learner to wrestle with alternative solutions and take risks in thinking (Manouchehri, 1997, NCTM, 2000). Thinking about alternatives in solutions allowed the learner to expand problem solving skills and gain insight into the content that can be reapplied in later situations (Manouchehri, 1997). Swartz (1982) expounded on the importance of students to problem solve using a variety of strategies to gain understanding. The problem solving process, therefore, promoted the development of thinking skills (NCTM, 2000).

Problem solving often began, for both science and mathematics, in problem posing (NCTM, 2000, NRC, 1996). Children were noted to have a natural curiosity about the world in which they live (NCTM, 2000). These natural curiosities led them to question and explore the world around them. Students built knowledge through the natural problem solving process (Goodnough & Nolan, 2008; NCTM, 2000). With problem solving, students were expected to find an answer to a question which is not readily known (NCTM, 2000). The processes students go through to solve the problem helped them build an understanding (NCTM, 2000). Unlike rote memorization, the processes of problem solving also provided a means for teachers to create a mathematics and science classroom that fostered teaching through conceptual learning (Molina et al., 1997, NCTM, 2000).

Polya was a mathematician who greatly influenced problem solving strategies in mathematics (NCTM, 2000). Some of the most common strategies he described include “using diagrams, looking for patterns, listing all possibilities, trying special values or cases, working backward, guessing and checking, creating an equivalent problem, and creating a simpler problem” (NCTM, 2000, p. 54). These strategies were used as students solve problems within a context (NCTM, 2000). For example, children in a science classroom may have used a magnifying glass to observe organisms or objects to answer a question. Their observations then led them to look for patterns or to list common features, and this was very similar to students in a mathematics class examining and sorting pattern blocks to determine which ones fill a space. In both scenarios students were actively involved in problem solving.

Reasoning and Proof. Reasoning and proof helped students develop logical thinking to decide if an answer makes sense. Students developed guesses or conjectures about concepts, experiments, or observations (NCTM, 2000; NRC, 1996). In mathematics, students noted patterns. They used reasoning and proof processes to determine if the “patterns are accidental or if they occur for a reason” (NCTM, 2000, p. 56). Reasoning and proof included the ability of students to use counterexamples to disprove a conjecture (Chick, 2007; NCTM, 2000). Similarly in science, students used reasoning and proof processes in experiments and tests to determine if the results are consistent (NRC, 1996). Reasoning and proof were especially critical in science due to the nature of science requiring evidence of conclusions based on experiments and observations (NRC, 1996).

Tools became a helpful resource in science and mathematics for students to be able to reason and provide proof of their solution (NCTM, 2000; NRC, 1996). Students were expected to use concrete materials as a means of investigating conjectures held about concepts (NCTM, 2000; NRC, 1996). Tools for mathematical calculations often were used in science as a means of providing evidence for the conjecture: measurement devices for time, length, capacity, temperature, and weight. Tools in mathematics for reasoning and proof may have involved measurement devices but they also might be strings or numbers or calculations or diagrams.

Communication. As students were involved in problem solving and reasoning and proof of a situation, communication became another common process that emerges. Communication involved talking, writing, and listening, (NCTM, 2000) about the mathematics or science concept being learned. Communication allowed students to refine their thinking and cement ideas (Goodnough & Nolan, 2008; NCTM, 2000; Zull, 2002). Classroom discourse became a critical arena for students to share, question, and revisit ideas (NCTM, 2000). Students benefited from learning about the way other students in the class thought about and solved problems (NCTM, 2000). Communication also aided students in the development of more formal mathematical language (NCTM, 2000). Since science was based on experiments and observations, communication in science was important for students to express their understanding, make predictions, and develop conclusions of experiments and observations (Goodnough & Nolan, 2008; NRC, 1996). In mathematics communication became important as students presented their proofs. The other students in the classroom needed to be able to understand the reasoning behind the proof (NCTM, 2000).

This process of students and teachers discussing the science and mathematics was called discourse. Teachers played a critical role in the form and function of the classroom discourse

(Goodnough & Nolan, 2008; NCTM, 2000; Newton & Newton, 2001; Zull, 2002). Furthermore, subject matter knowledge of the teacher could influence the type of discourse (Newton & Newton, 2001). Teachers with limited subject matter knowledge would have difficulty fostering discourse for ideas they themselves did not know or understand. Teachers may have found it difficult to relinquish control of the learning context to allow for students to fully communicate their learning (Goodnough & Nolan, 2008). In order for preservice teachers to develop communication skills in students and promote discourse in the classroom, Kistler (1997) recommended that preservice teachers also needed to learn how to communicate about mathematics.

A specialized means of communication was through the use of technology and more specifically, computers. Computer mediated communication [CMC] provided a means for communication of ideas and concepts that can move potentially beyond the classroom (Spears, Postmes, Lea, & Wolbert, 2002). Computer mediated communication included electronic mail [e-mail], weblogs [blogs], or discussion boards (Bull, Bull, & Kajder, 2003; Repman, Zinskie, & Carlson, 2005; Wiegel & Bell, 1996). Wiegel and Bell (1996) found that students who used electronic communication shared information more than students who hand wrote their reflections. Computer mediated communication may also have acted as an equalizer in the sense that everyone with access had equal opportunity to contribute (Spears et al, 2002). Bull et al. (2003) used blogs as a forum for preservice teachers to share thoughts and ideas on texts and current topics in the news.

Connections. Connections allowed students to have a deeper understanding of a concept (NCTM, 2000; Zull, 2002). Connections could be made within topics, to other subjects, or to experiences (NCTM, 2000). Furthermore, connections helped students to link the concepts rather than learn isolated facts (NCTM, 2000). In mathematics, students may have worked on a task determining the volume of pairs of cones and cylinders with the same height and base. They could then make connections between the two volumes to make a generalization about the volume of cones and cylinders with the same height and base. In science, students may have taken their knowledge of what makes a simple circuit to make connections to series or parallel circuits.

Mathematics was an integral part of science, commerce, and the everyday world (NCTM, 2000). As such students in a science class were expected to be making connections to the mathematics involved in the science (NCTM, 2000). In studying the way the brain operates, Zull (2002) determined that students make connections when they use language to express their learning and test ideas. He found that when children use language, they use it to connect old ideas with new ideas. Therefore, making connections and communicating those connections became critical to student learning (Zull, 2002). Journal writing could provide a way for students to make connections between the hands-on experiences and the concept (Bleicher, 2006).

Representations. As students solved problems in mathematics and science they relied on representations to express ideas (Davis & Petish, 2005; Justi & van Driel, 2005; NCTM, 2000). Representations were not only what occurs on paper, but what also occurs in the mind (NCTM, 2000; Zull, 2002). Symbols, diagrams, graphs, and images were examples of representations (NCTM, 2000; Posner, Strike, Hewson, & Gertzog, 1982). In science as students tested a simple circuit consisting of a battery, a light bulb, and connecting wire, students represented on paper their various tests. Similarly, in mathematics, as students determined combinations of outfits to wear, they represented the combinations through colored squares or drawings labeled by their own invention. Concrete tools allowed students to begin to develop more complex forms of representations (NCTM, 2000). However, there were situations in which representations may serve as an obstacle if the learner does not know how to interpret the representation (Heywood, 2007). For example, if students in a classroom did not understand how base 10 blocks represented the number system, this would be an obstacle in using the representations. Furthermore, representations allowed students to relate concepts to the real world and are important in communication, reasoning and proof, and problem solving (NCTM, 2000).

Different types of representations were used in teaching (Davis & Petish, 2005). Mental representations differed from instructional representations (Davis & Petish, 2005, Justi & Gilbert, 2000; Zull, 2002). Instructional representations included real world applications, physical demonstrations, and visual aids (Davis & Petish, 2005). Mental representations included mental images and ideas created in the mind (Zull, 2002). In Ball's (1988) study of classroom teachers, she found that teachers who used a mixture of symbolic forms with drawings enabled the students to develop meaning through the representations. Zull (2002) also found that images played a key role in students processing new information to existing neural networks. Problems may arise when teachers selected representations that did not align with the learning goals (Davis & Petish, 2005). Furthermore, choice in representations conveyed a teacher's knowledge and beliefs about mathematics and impacts student learning of the content (Ball, 1996; Davis & Petish, 2005). It was important that students develop clear and accurate mental representations of concepts. This indicated that teachers must also carefully choose the instructional representation for a concept, in order to help students make connections with the representation to help develop mental representations.

Common Teaching Approaches in Mathematics and Science

Along with common processes in mathematics and science were common approaches in teaching mathematics and science. Reflection (Bleicher, 2006; Cannizzaro & Menghini, 2006; Heywood, 2007; Hill, 1997; Manouchehri, 1997), inquiry (Manouchehri, 1997; Morrison, 2008; NRC, 1996; Weld & Funk, 2005), assessment (Manouchehri, 1997; NCTM, 2000; NRC, 1996), discourse (Akerson, 2005; Goodnough & Nolan, 2008; Williams & Baxter; 1996; Woodruff & Meyer, 1997), and tools for conceptual development (Bleicher, 2006; Justi & Gilbert, 2000; NRC, 1996; Sriraman & Lesh, 2007) were common to science and mathematics teaching.

Reflection

Reflection of thinking allowed students to examine past experiences and merge the new information with the old (Manouchehri, 1997). Cannizzaro and Menghini (2006) used the process of reflection to aid preservice teachers to expand on conceptions of definitions other than the traditional definition. Hill (1997) found that reflection allowed preservice teachers to present and clarify their understanding of mathematics. Through the reflection process preservice teachers also realized the significance of relational learning (Hill, 1997). Reflection provided a means for learners to make connections between experiences and concepts (Bleicher, 2006). Reflection also helped in the conceptual change process by providing time to examine conflicting ideas and examine new ideas (Heywood, 2007). Philipp, Thanheiser, and Clement (2002), in a course that integrated content and children's mathematical thinking, used reflection as a means for preservice teachers to make connections between the content and pedagogy.

For teachers, reflection was considered a part of the teaching process (Heywood, 2007). Teachers reflected on their own knowledge, their own teaching practice, and the learning of the students (Heywood, 2007; Howitt, 2007; Kelly, 2000). Teachers were expected to reflect on student reasoning when giving an explanation in order to provide an appropriate counter response (Beyer & Davis, 2008). Therefore, reflection could promote pedagogical content knowledge through the examination of practice, learning, and knowledge of students (Davis & Petish, 2005; Heywood, 2007; Kelly, 2000).

Inquiry

Inquiry and inquiry-based instruction have been promoted in the *National Education Science Standards* (NRC, 1996), by researchers of mathematics education (Manouchehri, 1997), and in science education (Morrison, 2008; Weld & Funk, 2005). Inquiry involved authentic questions, often based on learners' experiences, followed by investigations to answer the questions, and a reflection on the results of the investigations (Morrison, 2008; NRC, 1996). Inquiry-based teaching has been credited for students developing a deeper understanding of the nature of science (Morrison, 2008; Weld & Funk, 2005). Students may sometimes have experienced frustration when examining science through inquiry (Morrison, 2008). This frustration may be due to the fact that the teacher was not giving them the answers, and the students have to work through the unknown to find answers. Teacher education programs should have aided preservice teachers in developing schemes of inquiry and provide inquiry explorations (Manouchehri, 1997; Morrison, 2008; Weld & Funk, 2005). Developing schemes of inquiry in teachers helped them understand the inquiry process and experience lessons approached with inquiry. For teacher training programs schemes of inquiry could be developed and built upon throughout the program in content courses (Sanger, 2006; Weld & Funk, 2005) and methods courses (Akerson & Donnelly, 2008; Morrison, 2008).

The National Science Education Standards (NRC, 1996) called for science teachers to base their teaching on using inquiry. Morrison (2008) found that many teachers, due to lack of inquiry-based science experiences, needed opportunities to experience inquiry activities and reflect on their learning. Appleton and Kindt (1999) found that teachers' use of "cook-book" lessons limited inquiry due to the predictable nature of such lessons. A key component of inquiry-based teaching revolved around authentic questions. Morrison (2008) found that most of his preservice teachers in a science methods course were able to generate authentic questions; however, some had difficulty generating good questions. In a study comparing elementary preservice teachers in an inquiry-based chemistry course and secondary teachers in a traditional course, Sanger (2006) found that the elementary preservice teachers performed as well or better on chemistry content questions than the students in the traditional class. Experiences with inquiry-based teaching and learning have been found to impact elementary preservice teachers' conceptions of science, address misconceptions, and build confidence in science skills (Bhattacharyya, Volk, & Lumpe, 2009; Sanger, 2006; Weld &Funk, 2005). After taking a chemistry course for preservice elementary teachers using inquiry-based methods, the participants' felt confident in their science knowledge (Sanger, 2006). Weld and Funk (2005) noticed similar results in a life science course for elementary preservice teachers.

Assessment

Teacher education programs needed to provide preservice teachers methods in analyzing students' cognitive abilities; otherwise known as assessment (Manouchehri, 1997). Assessment was a necessary part of teaching. The standards documents recommend that assessments operate throughout a teaching program and not just at the end (NCTM, 2000; NRC, 1996). Assessments provided insight to teachers as to what students know or don't know about mathematics and science (NCTM, 2000; NRC, 1996). However, assessments only measured certain aspects of student knowledge and have to be interpreted in the scope of what the assessment was designed to measure (NCTM, 2000). Furthermore, the national standards recommend that teachers assess student knowledge throughout a lesson including when students are discussing, conducting experiments and trials, or completing journal or open-ended responses (NCTM, 2000; NRC, 1996). Teachers assess students through questions, written modes, and performance (Wang, Kao, & Lin, 2010).

Discourse

Discourse was another aspect of reformed based mathematics (Williams & Baxter, 1996) and science classrooms (Akerson, 2005). Discourse helped facilitate development of new knowledge (Williams & Baxter, 1996). In order for discourse to promote this development of new knowledge, certain factors were to be in place (Williams & Baxter, 1996). First of all, the classroom environment had to be one that encouraged students to share their thinking (Williams & Baxter, 1996). Teachers were to determine expectations for discourse among the class members (Williams & Baxter, 1996) and to provide modeling (Goodnough & Nolan, 2008). Discourse did not mean that students just have conversations with one another (Williams & Baxter, 1996). Students would experience difficulties in group interactions in which some students dominated the conversation over other students (Goodnough & Nolan, 2008). The classroom teacher had to know how to facilitate the discourse to ensure that students are gaining knowledge from the conjectures, explanations, or contradictions that are presented (Williams & Baxter, 1996; Woodruff & Meyer, 1997). Kistler (1997) recommended that elementary preservice teachers should experience discourse in their preparation program.

Discourse provided a venue for students to learn more deeply about science (Akerson, 2005). Akerson (2005) observed teachers starting with questions and encouraging discussion in order for students to gain a better understanding of the science concepts. In order to bridge the gap from the prior knowledge and experiences of the students, discourse in the form of group discussion and inquiry about a concept is critical to promote connection of concepts, vocabulary, and experiments with the old knowledge (Woodruff & Meyer, 1997). Discourse provides an opportunity for students to reason and construct information together which promotes reasoning (Akerson, 2005). As students reason through the discourse process, teachers make decisions of what to say, questions to ask, and information to provide (Heywood, 2007; Williams & Baxter, 1996). Kelly (2000) identified that discourse among preservice teachers helped them clarify misconceptions, discuss new ideas, and test new concepts. Furthermore, discourse aids students in making connections between their prior knowledge and new concepts (Kelly, 2000).

Tools for Conceptual Development

Experiences impacted the way students learn and understand (Hoffer, 1993; Speilman & Lloyd, 2004; Zull, 2002). Concrete tools offered opportunities for direct experiences and added opportunities for learning (Hoffer, 1993; Marek & Cavallo, 1997; Zull, 2002) as well as supporting real world mathematical and science situations (Jurdak & Shanin, 2001; NRC, 1996). After studying the way the brain works, Zull (2002) concluded that students must have physical interactions to connect ideas in the brain with the actual actions of objects as well as connecting the concrete ideas to abstract ideas.

The National Research Council (1996) recommended that students must have tools in order to be able to directly investigate scientific phenomena. Tools for developing concepts are often in the form of models (Justi & Gilbert, 2000). "A model can be taken to be a representation of an idea, object, event, process, or system" (Gilbert & Boulter, 1995 as cited in Justi & Gilbert, 2000, p. 994). Learning aids in mathematics are known as manipulatives (Sriraman & Lesh, 2007). Manipulatives should precede symbolic notation (Sriraman & Lesh, 2007). The use of concrete tools in mathematics and science lessons is often referred to as "hands-on" (Bleicher, 2006). Hands-on teaching can be used to introduce or develop a concept (Bleicher, 2006).

Concrete tools played a role in linking school to real world activities, connecting subject matter, and building conceptual understanding (Jurdak & Shanin, 2001). After studying how plumbers and students solved the same given problems, Jurdak and Shanin (2001) found there to be a paradox between the type of mathematics completed in school and the type used in the workplace. They recommended that "one possible approach is for the mathematics curriculum to build bridges between conceptual tools and concrete tools" (Jurdak & Shanin, 2001, p. 314). However, building bridges between conceptual tools and concrete tools was a complex teaching process that required teachers' pedagogical content knowledge (Chick, 2007; Davis & Petish, 2005).

Merely giving students concrete materials did not ensure that connections will be made or deep levels of understanding will be attained (Justi & Gilbert, 2000). When teachers plan lessons, choices were made as to the representations or models to be used in the lesson (Chick, 2007; Goodnough & Nolan, 2008). Teachers discarded some options and choose other options based on strengths and weaknesses each option offers (Chick, 2007). Teachers analyzed the representation, model, or illustration in relation to how closely the tool will aid students in obtaining the new knowledge based on students' prior knowledge and level of thinking (Chick, 2007). Once a tool had been selected, teachers then decided how the tool would be used in the learning experience (Chick, 2007). Teachers determined questions, explanations, and tasks involving the tool while keeping in mind the learning objective for the lesson (Chick, 2007;

Goodnough & Nolan, 2008). Teachers were expected to provide a means for students to make connections from the experiences with concrete tools (Bleicher, 2006)

Examples of situations or problems also served as a tool for building understanding (Chick, 2007; Zull, 2002). Chick (2007) recommended that teacher education programs aid future teachers in discriminating between fruitful and fruitless examples. Counter-examples were useful tools in helping students think about extensions and depth in problems (Chick, 2007). In order for teachers to produce counter examples, they needed experience in examining the nuances of examples in order to determine which examples would be appropriate (Chick, 2007).

Manipulatives were often thought of as a tool for developing concrete experiences in mathematics. Fuller (1996) found that teachers use manipulatives in various ways. Teachers who choose to demonstrate with the manipulative while the students look on represent a content-focused approach (Fuller, 1996). Whereas teachers who had students use the manipulative themselves indicate a learner center approach (Fuller, 1996). Zull (2002), in considering the way young children naturally examine what is in front of them, recommended that teachers put objects in front of the students to allow the students to explore.

Software applications served as another tool for conceptual development. Hoffer (1993) used three-dimensional software to investigate geometric properties of polyhedra. The software allowed students to conjecture and make proofs about the polyhedra (Hoffer, 1993). Students moved between physical models of polyhedra to software generated models of polyhedra to test mathematical ideas (Hoffer, 1993). After further investigations, Hoffer (1993) suggested that the experiences allowed the students to apply the scientific method of exploration, research, and determining conclusions.

Use of concrete tools played a powerful role in teacher training programs as well (Hill, 1997). Since preservice teachers experiences with mathematics often consist of rules and postulates, the use of manipulatives, models, and alternative approaches allowed the preservice teacher to confront past experiences and develop relational understanding of mathematics (Hill, 1997). Working with children in schools allowed preservice teachers to put into practice the use of same or similar manipulatives, models and alternative approaches experienced in teacher preparation classes (Hill, 1997). Furthermore, Hill (1997) speculated that work with children may allow new teachers to recognize that the 'rule and postulates' view of mathematics that they experienced is not the most effective way of teaching mathematics (Hill, 1997). Moreover, Hill (1997) found that when preservice teachers used concrete experiences in courses and with students in field placements, it set the stage for preservice teachers to achieve conceptual change due to bolstering self-confidence in teaching, gaining a sense of accomplishment, and deepening of mathematical understanding.

Preparation of Elementary Teachers

Teacher education programs established a process that allows preservice teachers opportunities to develop the recommended skills of designing, planning, and implementing lessons using standards-based practices to meet the needs of the students (Manouchehri, 1997; Noori, 1994; Speilman & Lloyd, 2004) and to develop an understanding of the complex task of teaching (Grossman et al., 2009). This preparation program typically occurred in three phases: subject matter, theory of education, and pedagogy (NCATE, 2010). During the first phase, preservice teachers took general content courses in various departments within the institution. Preservice teachers then move into the teacher preparation portion of their program. Institutions partnered with nearby school systems to provide clinical teaching experiences (ACEI, 2011).

Methods courses often included part-time clinical practice. Teacher candidates experienced an increase in responsibilities as they complete various field experiences (ACEI, 2011). Methods courses were often taught by subject specific professors and utilize a combination of on campus and clinical practice in the field. Student teaching, meant to solidify the preservice teacher's knowledge of teaching (Fennel, 1993), was the final phase that takes place after preservice teachers have completed their methods courses. It consisted of a full-time immersion in a school setting where the preservice teacher assumes the role of the classroom teacher.

Improving Teacher Education Programs

With the call for improvement of the preparation of elementary teachers (National Commission on Excellence in Education, 1983; U. S. Department of Education, 2011), efforts had been made to improve elementary teacher education programs. The federal government recently established initiatives for top teacher preparation programs based on a linking process of student test scores and the teacher's preparation institute. In 1997, Texas organized a commission of K-16 educators to design guidelines for elementary teacher programs in mathematics (Molina et al., 1997). The purpose of the commission was to design an elementary teacher program which would strengthen elementary teachers in the teaching of mathematics (Molina et al., 1997). Furthermore, the commission recognized the importance of aligning teacher education programs with the standards as advocated by the National Research Council (1989) and the National Council of Teachers of Mathematics (1989, 1991) (Molina et al., 1997). The commission recognized that mathematics is more complex than a series of formulas, that technology has affected the way mathematics is used in the real world, and that mathematics requires sense-making and the development of mathematical sophistication (Molina et al., 1997). With the recognized changes in mathematics and society, changes are necessary in teacher education programs (Kistler, 1997; Molina et al., 1997). Furthermore, a lack of performance in students could be attributed to the lack of mathematical preparation of teachers (Molina et al., 1997).

In order to improve the education of elementary teachers, faculty were expected to model the instructional practices as advocated as well (Kistler, 1997; Molina et al., 1997; Olgun, 2009). Preservice teachers needed experiences designed by the teacher educators to promote connections between the content and the pedagogy (Bleicher, 2006; Kelly, 2000; Manouchehri, 1997; Molina et al., 1997; Tal et al., 2001). Teacher candidates entered the program with varied personal feelings about mathematics (Harkness, D'ambrosio, & Morrone, 2007). In particular, elementary preservice teachers may have had anxiety about mathematics (Gresham, 2007; Trujillo & Hadfield, 1999). "Mathematics anxiety is a feeling of helplessness, tension, or panic when asked to perform mathematics operations or problems" (Gresham, 2007, p. 182). Education programs had to take into account students' prior experiences and provided experiences that allowed the preservice teachers to shift or alter their belief system to envelop the ideologies of the program (Ball, 1988; Heywood, 2007; Kelly, 2000).

Science and Mathematics in Elementary Teacher Education Programs

Teacher education programs came under criticism as well for the lack of preparation for teaching science and mathematics (De Villiers, 2004, Tal et al., 2001). De Villiers (2004) recommended teacher education programs needed to allow "sufficient opportunity for exploration, conjecturing and explaining" (p. 704). The author also suggested that if preservice teachers have not been exposed to mathematics that involves problem-posing, conjecturing, refuting, and reformulating, then how can they adequately stimulate this in their classrooms? Similarly, Tal et al. (2001) determined that teacher education programs must provide experiences that allow new teachers to understand Science-Technology-Society (STS) concepts with a focus on the process of gaining scientific literacy. Providing students with opportunities to explore, investigate, and reason would also aid preservice teachers in challenging deeply held beliefs about mathematics (Manouchehri,1997; Philipp et al., 2002) and science (Heywood, 2007; Kelly, 2000), and replace those beliefs with reform-minded ones. Spielman and Lloyd (2004) found that the use of reform curricula with preservice teachers had a positive impact on their beliefs about mathematics. Similarly, researchers expressed that preservice teachers' involvement in courses aligned with Principles and Standards for School Mathematics (NCTM, 2000) would produce more effective elementary teachers (Alsup, 2003; Kistler, 1997).

Disparities in Teacher Education Programs

Consensus had not been reached as to the best manner for preparing elementary teachers to teach (Even et al., 1996). Shulman (1986) argued that content knowledge alone was not sufficient. Furthermore, he found that the curricular knowledge was most neglected in teacher education programs (Shulman, 1986). Similarly, Newton and Newton (2001) determined that all of the content preparation could not possibly prepare preservice teachers for classroom events and must include pedagogical training as well. Even et al. (1996), on the other hand, concluded that teacher education programs should focus on empowering teachers in decision making rather than employ curricula developed by "experts". After examining teacher education programs from six countries, Schmidt et al. (2007) found that countries with strong student test scores produced strong teacher education programs that focused on extensive content teaching along with practical pedagogical experiences.

Another disparity in teacher education had been attributed to the complexity of teacher education programs (Bales & Mueller, 2008). Teacher education programs involved education professionals from four distinct settings (Bales & Mueller, 2008). Preservice teachers worked with faculty in science and mathematics classes, faculty in education courses, practicing teachers in field experiences, and other school personnel (Bales & Mueller, 2008). Complications could occur in the development of the preservice teachers with such distinct units each with different agendas for the preservice teacher (Bales & Mueller, 2008).

Another factor that influenced teacher development programs was the content knowledge of the preservice teachers (Ball, 1988; Cannizzaro & Menghini, 2006; DeVilliers, 2004; Even et al., 1996; Matthews & Seaman, 2007). Preservice teachers had misconceptions and gaps of mathematical knowledge some of which has been attributed to poor or deficient mathematics experiences (Cannizzaro & Menghini, 2006; De Villiers, 2004). Similarly, studies revealed elementary preservice teachers have fragmented knowledge of mathematics (Ball, 1988; Even et al., 1996; Quinn, 1997). Performance by U.S. future educators, when compared to other countries' future educators, indicated weaker levels of knowledge in all areas of mathematics (Schmidt et al., 2007).

Deficiencies in science content knowledge have also been found (Davis & Petish, 2005; Harlow & Otero, 2006; Kelly, 2000). Kelly (2000) found the lecture and text based cookbook style science experiences were a limiting factor in the way preservice teachers thought about the nature of teaching science. Teachers themselves admitted to their own lack of content knowledge in teaching science (Hatton, 2008; Harlow & Otero, 2006). Justi and van Driel (2005) determined that teachers' content knowledge was the most important factor in how students learned science. Furthermore, a connection existed between the level of science knowledge and the pedagogical content knowledge in science teachers (Appleton, 2008; Davis & Petish, 2005).

Mathematics Courses for Elementary Teacher Programs

In addition to efforts made by states to improve elementary teacher education programs, The No Child Left Behind Act (NCLB) (2002) created additional mathematics course requirements for elementary teacher education programs. Unfortunately, mathematics courses for elementary preservice teachers were often taught by faculty in the mathematics department with a traditional lecture based teaching format (Alsup, 2003; Manouchehri, 1997). This form of teaching continued the fragmented knowledge base preservice teachers already have in mathematics (Ball, 1988). In an effort to provide a reform model of mathematics, efforts were made on the part of multiple universities to establish mathematics content courses that relied on problem solving, conjecturing, conceptual development, and reasoning (Alsup, 2003; Emenaker, 1996; Even et al., 1996; Gresham, 2007; McLeod & Huinker, 2007). Problem solving allowed students to construct their own knowledge in an active learning environment (Alsup, 2003). Reform models in the science and mathematics content courses provided a continuum of reform-based teaching as preservice teachers moved from content courses to methods class that also employed reform models of teaching (Cady et al., 2006). Even et al. (1996) found that when preservice teachers participated in activities that challenged their previous notions of mathematics that they were able to clarify and reevaluate the meaning of mathematical ideas and mathematical instruction.

McLeod and Huinker (2007) incorporated the four main principles of mathematical knowledge of teaching (MKT), as determined by Hill et al. (2008), in a mathematics course for preservice teachers. One course focused on problem solving, communication, and reflection. Other courses focused specifically on geometry, discrete mathematics and statistics, and algebra. Students indicated improved confidence in their mathematical abilities. The researchers concluded that the problem solving course was the course that had the greatest impact on the teachers' mathematical knowledge of teaching (McLeod & Huinker, 2007).

Science Courses for Elementary Teacher Programs

Science departments similarly made attempts to improve courses for elementary preservice teachers (Harlow & Otero, 2006; Heywood, 2007; Sanger, 2006). As with mathematics, elementary teachers were found to be deficient in content knowledge of science (Heywood, 2007; Kelly, 2000; Rice, 2005; Summers et al., 2001). Elementary teachers often avoided teaching science (Appleton & Kindt, 1999; Howitt, 2007; Sanger, 2006) which has been attributed to their lack of confidence in their knowledge of science (Heywood, 2007; Kelly, 2000; Olgun, 2009; Weld & Funk, 2005). Just as with mathematics, teachers held negative views about teaching science (Fulp, 2002; Kelly, 2000). In comparison to other subjects, elementary teachers reported they have less confidence to teach science (Fulp, 2002; Weiss, 1994) and as a result may not teach science or may postpone the teaching of science (Appleton & Kindt, 1999). Furthermore, elementary preservice teachers attributed their prior negative experiences with science as a reason for a lack of confidence in teaching the subject (Weld & Funk, 2005). Content and methods courses, conducted in a non-traditional manner with a focus on inquiry-based teaching and learning, provided an opportunity for preservice teachers to experience science class in the manner that followed national standards on science teaching, as well as a means to boost confidence in the subject (Heywood, 2007; Howitt, 2007; Kelly, 2000; Olgun, 2009; Sanger, 2006).

Studies with preservice teachers on science content have occurred in content courses (Sanger, 2006; Weld & Funk, 2005) and methods courses (Davis & Petish, 2005; Dawkins, Dickerson, McKinney, & Butler, 2008; Gee et al., 1996; Heywood, 2007; Howitt, 2007; Kelly, 2000; Olgun, 2009; Rice, 2005; Wang et al. 2009). Elementary preservice teachers often lacked content knowledge in science (Rice, 2005; Summers et al., 2001; Weld & Funk, 2005) and held naïve views about science (Heywood, 2007). Content courses in science, just as in mathematics, were often presented as lecture based classes with cook-book labs (NRC, 1996). As a means of developing content and pedagogical knowledge, researchers focused on active learning (Olgun, 2009), inquiry-based teaching (Harlow & Otero, 2006; Morrison, 2008; Sanger, 2006), and misconceptions about science (Dana, Campbell, & Lunetta, 1997; Dawkins et al., 2008; Heywood, 2007). Heywood (2007) found that addressing misconceptions with elementary preservice teachers was effective in building their science knowledge for teaching. Justi and van Driel (2005) recommended that teachers should be taught about scientific models and how to use models. Wang et al. (2009) recommended that preservice teachers' concepts of assessment in pedagogical practices should be addressed in the methods class as well. Kelly (2000) found that preservice teachers' experiences in a constructivist-based methods class, along with field experiences, to be effective in helping the preservice teachers gain an understanding of what it means to teach science.

Teacher Beliefs and the Impact on Practice

Teachers made decisions about teaching practices based on underlying beliefs and past experiences (Kelly, 2000; Manouchehri, 1997). Beliefs and knowledge were knitted together and cannot be separated from one another (Manouchehri, 1997). Hancock and Gallard (2004) defined beliefs "as an understanding held by an individual that guides that individual's intentions for actions" (p. 281). Shaw and Cronin-Jones (1989) shared that researchers could not look at knowledge alone; beliefs had to be taken into account. Similarly, Poole (1995) argued that beliefs and values could not be ignored and were embedded within all aspects of education.

Beliefs were developed through childhood (Poole, 1995; Waters-Adams, 2006). New experiences caused an individual to examine the experience in relation to their belief system (Pehkonen, 2001). Negotiations were then made with the new experiences and existing beliefs (Pehkonen, 2001). People could change their beliefs and choose differing belief systems from youth (Pehkonen, 2001; Poole, 1995).

Preservice teachers entered their teacher training programs with existing notions and ideas about teaching and learning based on their experiences and ultimately beliefs (Pajares, 1992; Shaw & Cronin-Jones, 1989). These belief systems positively or negatively impacted preservice teachers' attitudes (Tosun, 2000). However, field experiences and methods classes could modify or reinforce belief systems (Hancock & Gallard, 2004). Reform based preparation programs could also positively impact preservice teachers' beliefs and attitudes (McGinnis et al., 1998). However, Waters-Adams (2006) observed teachers, whose experiences in school were different from the methods of their teacher training program, which led to a struggle to teach according to the espoused methods.

Researchers examined how belief systems impact various aspects of teaching mathematics (Ball, 1988; Cannizzaro & Menghini, 2006; Fuller, 1996; Martin et.al., 2005). A teacher's view of mathematics included "beliefs about mathematics, beliefs about oneself as a learner and user of mathematics, beliefs about mathematics teaching, and beliefs about mathematics learning" (Pehkonen, 2001, p.14). Teachers' beliefs about mathematics affected the way in which the teachers designed the learning environment (Pehkonen, 2001). A teacher whose goal was to make sure students write proofs similar to the textbook had different goals than a teacher who wanted to aid students to make sense of the proofs and the reasoning process of determining proofs (Martin et.al., 2005). Furthermore, teachers who focused on making tasks “fun” held different beliefs from teachers who wanted students to complete tasks that were worthwhile and significant to learning mathematics (Ball, 1988). Mathematics classes in which the teacher believes mathematics was about following procedures and rules looks completely different from a class in which the teacher believed students should develop understanding and reflective thought towards mathematics (Ball, 1988). Most significantly was that teacher beliefs about what it means to do mathematics was conveyed in the teaching of the mathematics and directly impacted how students thought about mathematics (Ball, 1988; Pehkonen, 2001).

Cannizzaro and Menghini (2006) designed research to improve the reflective practice of teachers in their teaching “towards the thinking of others and towards changes in one’s own knowledge, beliefs, and didactical practice” (p. 370). The teachers in the study realized the student responses were different in different classes depending on how the teacher approached the problem and the beliefs the teacher had about the ability of her students. Similarly, Fuller (1996) found after studying novice and experienced teachers that all of the teachers believed that showing and telling students how to solve problems exemplified a good teacher. This indicated that teachers needed to challenge their thinking about the dynamics of mathematics and the role of the teacher in the mathematics classroom (Fuller, 1996).

Similarly, researchers examined teacher beliefs about science as well (Poole, 1995; Shaw & Cronin-Jones, 1989; Waters-Adams, 2006). Teacher beliefs about science were influenced by childhood experiences as well as teacher training programs (Water-Adams, 2006). Poole (1995) concluded that within science education not only do individual beliefs systems affect the way science is taught but that science was also affected by society. Society’s beliefs about science were indicated by the importance on science in the education system, the resources that were provided to teach the subject, and the decisions about what was taught in science (Poole, 1995).

Shaw and Cronin-Jones (1989) examined beliefs of elementary and secondary preservice teachers. They recommended that methods courses help elementary preservice teachers develop their belief systems. Water-Adams (2006) determined that pedagogical decisions were based on a teacher's beliefs about education. Teacher actions may result from reactions to classroom events that occur spontaneously, from habit, or from carefully considered pedagogical choices (Martin et. al., 2005; Waters-Adams, 2006). Decision making was affected by a person's emotions, cognition, and will (Poole, 1995).

It was recommended that teacher education programs take into consideration preservice teachers' underlying beliefs when making decisions about the program (Manouchehri, 1997; Philipp et al., 2002). Beliefs were the filter through which teachers translate the knowledge of mathematics and science and the pedagogy of teaching (Manouchehri, 1997). By the time preservice teachers entered teacher education programs, they had been enculturated through their own school experiences (Kelly, 2000; Manouchehri, 1997). Those school experiences were often comprised of isolated facts, disconnected concepts, and a surface level of understanding (Heywood, 2007; Kelly, 2000; Manouchehri, 1997) in which students only learned information for short term purposes (Heywood, 2007). In a survey of preservice teachers at the beginning of a science methods course, Kelly (2000) found that over the half of the students held negative beliefs about science and considered it to be too difficult to learn, boring, and required too much rote learning. Due to the deep level of enculturation, teacher education faculty were expected to undo what preservice teachers learned in the K-12 setting (Ball, 1988) as well as in content college classes (Kelly, 2000).

Teacher education programs, in order to make a shift in beliefs, had take into consideration what preservice teachers know and think about mathematics (Ball, 1988; Green, Piel, & Flowers, 2008) and science (Heywood, 2007). Manouchehri (1997) concluded that due to the enculturation of a traditional pedagogy, preservice teachers may not see the value of the reform pedagogy nor focus their attention on the methods being used in the education classes. Preservice teachers were unlikely to change or alter their existing beliefs unless they are challenged to closely examine the beliefs they already hold (Feiman-Nemser & Buchmann, 1986). Even with challenges to existing beliefs, some teachers held on to misconceptions and some were resistant to change (Gee et al., 1996; Heywood, 2007). Monhardt (2009) found that elementary preservice teachers believe that they have sufficient science knowledge when in fact they often do not. College experiences that allowed preservice teachers to solve problems, explore, analyze, and present reasoning and proof of solutions created opportunities for preservice teachers to challenge and change beliefs (Kelly, 2000; Manouchehri, 1997). New teachers also often taught in naïve ways (Heywood, 2007). They often taught through telling rather than through insightful experiences (Heywood, 2007). Preservice teachers were also concerned with their own teaching rather than student learning (Akerson, 2005). Furthermore, in schools, literacy and mathematics often took precedence over science teaching (Heywood, 2007). New teachers did not spend as much time teaching science due to the pressures for students to perform well in reading and mathematics (Heywood, 2007).

Student Teaching

Teacher candidates practice taught on a small scale during their methods classes. When preservice teachers entered full-time student teaching, it was expected that they would apply what they learned during methods courses to student teaching (Grossman et al., 2009). Preservice teachers were provided this opportunity during student teaching. Student teaching was the pinnacle of the teacher preparation program and some considered the most influential experience. However, the college or university had little control over the student teaching experience. Preservice teachers often had the "luck of the draw" when being assigned to a cooperating teacher (Bolton, 1997).

The cooperating teacher played a powerful role in the development of the student teacher (Putnam, 2009). Preservice teachers often were unfamiliar with the school and practices of the cooperating teacher. Bianchini and Cavazos (2007) suggested that beginning teachers need help negotiating the school culture and the culture of the students. Student teachers were required to teach in a classroom that is designed and controlled by the cooperating teacher (Bolton, 1997). This gave the cooperating teacher considerable power during the student teaching experience. This meant the student teacher and the cooperating teacher had to establish and maintain clear lines of communication (Bolton, 1997). The student teacher had to deal with the stress and anxiety of simultaneously being a student and a teacher (Bolton, 1997). Although novice teachers were enculturated by the cooperating teacher, both learned from one another through the mentor-mentee relationship that develops during student teaching (Crawford, 2007). This relationship that developed between cooperating teacher and student teacher often caused student teachers to place more relevance on the role of the cooperating teacher than experiences from the teacher preparation program (Securro, 1994).

Preservice teachers faced difficulties during their student teaching experience (Bolton, 1997; Fennell, 1993). Some struggled with student teaching despite doing well in university courses (Bolton, 1997; Tracy, Follo, Gibson, & Eckart, 1998). Student teachers entered into the student teaching experience feeling unprepared (Dana, 1992). Student teachers had concerns for survival, teaching situations, and student concerns and issues outside of student teaching (Smith & Sanche, 1993). Classroom management was a concern as well (Bolton, 1997).

Student teachers often adopted the teaching practices of the cooperating teacher (Putnam, 2009). This sometimes meant a student teacher shifted to more teacher oriented practices (Putnam, 2009) that were at odds with the pedagogical teaching from their university courses. Student teachers may have been taught reform methods of teaching in university courses but this was at odds with the type of science and mathematics teaching they experienced in student teaching (Crawford, 2007; Leonard, Boakes, & Moore, 2009). Additionally, cooperating teachers implied that methods taught at the university were not the real-world of teaching (Batesky, 2001). Interaction with the cooperating teacher impacted and influenced the new teachers' beliefs about their teaching abilities (Philippou, Charalambos, & Leonidas, 2003). A preservice teacher in a study by Philippou et al. (2003) worked with a traditional teacher and successfully taught a different way. However, another preservice teacher tried to teach differently from the traditional style of her cooperating teacher and it was not successful (Philippou et al., 2003). She felt dissatisfaction from her cooperating teacher and this affected how she felt about teaching mathematics. Crawford (2007) noticed that skepticism of reform practices develop during student teaching due to the culture clash of the assigned classroom and the university philosophy.

Conceptual Change

Teachers made decisions about teaching practices based on underlying beliefs and past experiences (Kelly, 2000; Manouchehri, 1997) and were unlikely to change or alter their existing beliefs unless they were challenged to closely examine the beliefs they already hold (Feiman-Nemser & Buchmann, 1986). The process of altering beliefs was known as conceptual change (Posner et al., 1982). Conceptual change began with learning. Learning occurred when new ideas interacted with old ideas and the new ideas were seen as ideas that made sense to the learner (Posner et al., 1982). People made judgments about new ideas based on data, verification, or confirmation (Posner et al., 1982). In this sense, learning was inquiry that involves the progression towards conceptual change (Posner et al., 1982). Assimilation was the first type of conceptual change (Posner et al., 1982). With assimilation students modified old ideas with new ideas (Posner et al., 1982). However, in some cases old ideas had to be completely replaced with new ideas (Posner et al., 1982). This dramatic change was called accommodation (Posner et al., 1982). Conceptual change often referred to this process of accommodation (Posner et al., 1982). Brown and Clement (1989) concluded that conceptual change must be the goal of teaching.

With recognition of the lack of strong mathematical skills (Ball, 1988; Manouchehri, 1997) and science skills (Heywood, 2007; Rice, 2005) and changes in teacher education programs (Gitomer, 2007; Molina et al., 1997), researchers examined the conceptual change of teachers (Heywood, 2007; Hill, 1997; Tal, 2001). Examining conceptual change of preservice teachers was necessary due to the different experiences that occur in the K-12 setting as compared to the reform teaching experiences in the teacher education program setting (Gee et al., 1996; Hill, 1997). Teacher education programs required student teachers to use teaching practices different from what they themselves experienced (Hill, 1997; Kelly, 2000). Conceptual change began with the learner losing faith in the original understanding of a concept (Posner et al., 1982). Cognitive conflict occurred when the learner became discontented or displeased with the existing notions (Heywood, 2007). This would not occur until the student encountered problems with the old ideas and became willing to accept new ideas (Posner et al., 1982). The process of reflecting on new ideas in the context of preexisting notions provided a means for learners to become discontent or displeased with their old ideas (Howitt, 2007). Zull (2002) argued that reflection becomes an important component to give the learner time to accept new ideas, since the learner holds deep emotions about their existing knowledge.

Experiences and teaching methods in teacher education programs provided an opportunity for preservice teachers to become dissatisfied with their existing notions and be willing to accept different ideas (Heywood, 2007; Kelly, 2000). Conflicting experiences could occur through the means of direct exploration and observation of a situation or incident (Kelly, 2000). Deliberations on readings also could provide an avenue for cognitive conflict (Heywood, 2007). Debates of contrasting views similarly allowed learners to become dissatisfied with the current view and more amenable to a new view (Heywood, 2007). Whatever the strategy employed, direct observation, readings of texts, or debates of contrasting views, preservice teachers' views were expected to be made explicit and the experience provide a cognitive dissonance (Heywood, 2007). However, the experience should not have made the learner feel discouraged about their present level of knowledge (Heywood, 2007). Furthermore, the new idea generated through the cognitive conflict experience had to be seen initially as being credible or able to fit into the learner's current schema (Posner et al., 1982).

The second phase of conceptual change was identified as the learner being able to understand new concepts (Posner et al., 1982). For new conceptions to be learned, the student had to be able to make sense of the ideas and representations (Posner et al., 1982). Learners then had to believe that the new concepts will solve the problem (Posner et al., 1982). Finally, learners had to feel that it was of value to put time and attention into the new concepts (Posner et al., 1982).

For elementary education majors who often held negative attitudes towards mathematics, the question begins with whether or not the preservice teachers believed themselves to be capable of learning mathematics (Hill, 1997) or science (Kelly, 2000). Therefore, the ability of preservice teachers to achieve conceptual change was further hindered by their lack of confidence in their own mathematical abilities (Hill, 1997) or science abilities (Kelly, 2000). Similarly, those with negative attitudes may have been more resistant to different methods of teaching (Freeman & Smith, 1997). In an effort to combat negative attitudes or lack of confidence, methods classes placed preservice teachers in classrooms to gain experience in teaching (Hill, 1997). Interaction with children was a very valuable experience for preservice teachers in the process of putting new ideas and concepts into practice (Heywood, 2007; Hill, 1997; Kelly, 2000). Work with students in schools was found beneficial for preservice teachers to fuse subject matter knowledge with pedagogical knowledge (Heywood, 2007; Kelly, 2000). Furthermore, children's positive response to preservice teachers provided encouragement for preservice teachers to teach in meaningful ways and may have helped preservice teachers recognize that change of thinking was necessary (Hill, 1997).

Conceptual change in thinking about science was also necessary (Heywood, 2007; Tal et al., 2001). In order for conceptual change in science to occur, teachers needed to assimilate new methods for teaching science (Tal et al., 2001). Heywood (2007) determined that science classes for preservice teachers should focus on misconceptions as a means of supporting conceptual change. Misconceptions could be used to promote reflection of science concepts. Reflection played a critical role in teachers replacing old ideas with new ideas (Heywood, 2007; Philipp et al., 2002; Zull, 2002).

Whether it was science or mathematics, teacher education programs had to be in alignment to help promote conceptual change (Gee et al., 1996; Heywood, 2007). A systematic process had to be in place in teacher education programs so that the experiences from content courses to methods courses to internship were in alignment (Heywood, 2007). Those experiences should have moved the new teachers from content specific knowledge to pedagogical content knowledge (Appleton, 2008; Heywood, 2007).

The Learning Cycle for Mathematics and Science Teaching

Just as mathematics and science content were intertwined so were the common approaches to teaching science and mathematics (NCTM, 2000; NRC, 1996). The learning cycle offered a way of incorporating similar teaching methods and use of tools for conceptual development (Chick, 2007; Fuller, 1996; Hill, 1997), discourse (Akerson, 2005; Heywood, 2007; William & Baxter, 1996), assessing student knowledge (Manouchehri, 1997; NCTM, 2000; NRC, 1996) inquiry-based teaching (Morrison, 2008; Manouchehri, 1997; NRC, 1996; Weld & Funk, 2005), and reflection (Bleicher, 2006; Hill, 1997; Manouchehri, 1997). Furthermore, the learning cycle offered a way for preservice teachers to confront their notions about mathematics and science and expanded their belief systems to undergo conceptual change.

Historical Context of the Learning Cycle

The learning cycle was not a new way to approach teaching (Lawson, Abraham, & Renner, 1989). Rather, in the learning cycle existed a natural form of learning that has persisted with child and adult (Lawson, Abraham, & Renner, 1989; Schmidt, 2008). On a physiological level, Zull (2002) found that sensory experiences entered in the sensory cortex of the brain were processed and actualized in the integrative cortex, and new ideas were tested in the motor cortex. From a sociological perspective, adults have observed children tasting, touching, smelling, and feeling the world around them, incorporating and reflecting the new ideas, and actively testing the new ideas (Schmidt, 2008; Zambo & Zambo, 2007). Similarly adults undergo the same processes when learning new material: consciousness of a new idea, investigation of the new idea, and finally use of the new idea (Schmidt, 2008). Schmidt (2008) described the natural learning cycle as consisting of “awareness, exploration, inquiry and action” (p.12).

Teaching consisted of a set of methods and procedures, some more effective than others (Lawson, Abraham, & Renner, 1989). Lack of subject matter knowledge, failure to implement effective teaching practices and routines, inability to gauge students and adjust instruction for individual needs, difficulty identifying what is going wrong in the teaching and learning environment, and surface level reflection of teaching experiences all were identified as ineffective teaching practices (Reynolds & Elias, 1991; Tracy et al., 1998). Adams, Cooper, Johnson, and Wojtysiak (1996) found that ineffective teaching practices created a learning environment that allowed students to be passive learners and less engaged in the teaching and learning process. In contrast to passive learning environments, Adams et al. (1996) found that solving problems and exploring real life situations, tenets of the learning cycle, were key components of a meaningful curriculum which promoted active learning, engaged students, and enacted more effective teaching practices.

The idea of appropriately designed learning situations was not a new one. Neal (1962) proposed that teaching techniques should focus on the development of critical thinking and this development of thinking depended largely on the design of the learning situation. It was during the late 1950s and early 1960s, in which educational reforms were in demand, that Atkin and Karplus (1962) developed their model for teaching and learning science which focused on the natural active learning of children and later became known as the learning cycle.

The development of the learning cycle began when Professor Robert Karplus spoke with his daughter’s second grade class (Lawson, Abraham, &Renner, 1989). Karplus began to think about the development of science in the elementary grades. In the late 1950’s and early 1960’s

Karplus developed learning units for the elementary grades that focused on the way students naturally approach and learn new phenomena. Karplus began to work with J. Myron Atkin on "discovery learning".

In their research from the early 1960's, Atkin and Karplus (1962) described a series of science experiments in which students came to understand the concept of magnetic field. In the series of experiments students were not led directly to the concept of magnetic field, but rather were led in a circuitous route to understand the concept from several points (Atkin & Karplus, 1962). Through the series of lesson observations Atkin and Karplus (1962) confirmed the idea that students should explore concepts, define and develop the concept from the experience, and apply the newly learned concept to a new situation. Furthermore, Atkin and Karplus (1962) offered that the teacher must never present scientific ideas in dictatorial ways due to the ever changing nature and knowledge of science. Initially, Karplus and Atkins (1962) only discussed invention and discovery (Lawson et al., 1989). They considered invention to be the development of a concept and discovery to be the verification of the concept in a new situation. The Karplus/Atkin model was later revised to include exploration (Lawson et al., 1989). At the time of the initial research by Karplus and Atkin, Professor Chester Lawson was developing a similar model of instruction (Lawson et al., 1989). Karplus and Lawson began working together on the Science Curriculum Improvement Study program in the 1960's and 1970's (Lawson et al., 1989). The three phases of the Atkin/Karplus model, exploration, invention, and discovery, were incorporated in the units developed for the Science Curriculum Improvement Study program (Kratochvil & Crawford, 1971). Lawson and others incorporated the same concepts in the Biological Sciences Curriculum Study (Withee & Lindell, 2006).

The phases of the learning cycle in the Atkin/Karplus model aligned closely with Piaget's theory of learning and in particular the processes of assimilation, accommodation, and organization (Abraham & Renner, 1983; Bybee, 1997; Kratochvil & Crawford, 1971; Marek & Cavallo, 1997; Renner & Lawson, 1973). Piaget concluded that children interact with the environment and encounter new concepts which create contradictions in thinking (Renner & Lawson, 1973). Piaget called this state of contradiction disequilibrium (Marek & Cavallo, 1997; Renner & Lawson, 1973). Children then assimilated the new information with the old information through exploration or adult guidance (Renner & Lawson, 1973). This followed similarly in the exploration phase of the learning cycle in which students were gathering and assimilating new information in a nondirected manner (Bybee, 1997). It was important that students in the exploration phase were allowed open-ended exploration with materials that explored the concept (Renner & Lawson, 1973) in order for students to examine differing avenues of thought (Lawson et al., 1989). Furthermore, directions given by the teacher should guide the students without telling them the concept they are to learn (Marek & Cavallo, 1997).

The invention phase followed the exploration phase (Bybee, 1997; Kratochivil & Crawford, 1971; Lawson et al., 1989). In the invention phase students were introduced to a new concept either by the teacher or another student (Kratochivil & Crawford, 1971). The process of accommodation in which new information replaced old information began at this point (Bybee, 1997). The discovery phase allowed for the learners to apply the newly learned concept to a new situation (Atkin & Karplus, 1962) and expand their understanding of the concept (Lawson, Abraham, & Renner, 1989). This completed the accommodation process and moved the learner from the initial state of disequilibrium to equilibrium (Bybee, 1997) and what Piaget named organization (Renner & Lawson, 1973).

The three phases have since been modified and interpreted by other researchers. However, the initial tenets still remained (Abraham & Renner, 1983). Karplus continued to call the phases of the learning cycle exploration, invention, and discovery until the 1970's (Lawson, Abraham, & Renner, 1989). In 1976, Karplus renamed the phases as exploration, concept introduction, and concept application (Karplus, 1976). Abraham and Renner (1983) expressed the phases as exploration, conceptual invention, and expansion of the idea. Marek and Cavallo (1997) thought of the phases as exploration, term introduction, and concept application.

5E Instructional Model of the Learning Cycle

The three phases were expanded to five phases, still incorporating the initial phases of the Karplus/Atkin model (Bybee, 1997), by Lawson and others on the Biological Sciences Curriculum Study (Withee & Lindell, 2006). The five phases included engagement, exploration, explanation, elaboration, and evaluation (Bybee, 1997). Chessin and Moore (2004) considered the model in terms of six E's: engage, explore, explain, expand, evaluate, and e-search. E-search was the use of electronic media, Internet research, presentation software, spreadsheet software, anywhere within the 5 E's (Chessin & Moore, 2004).

The engagement phase was what it sounds like, engaging the students (Bybee, 1997). During the engagement phase, teachers had students focus on an event or problem (Bybee, 1997). This may be accomplished through a question, a situation or a problem (Bybee, 1997; Marek et al., 2008). Teachers may even present a discrepant event as a means of engaging students (Marek et al., 2008; Tracy, 2003). Bircher (2009) even used juvenile literature to engage students in the concept. Students revealed their prior knowledge of the situation presented and raised questions during the engagement phase (Bybee, 1997; Withee & Lindell, 2006). As a result of the engagement phase students were curious and actively interested in the new concept, beginning the stage of disequilibrium (Bybee, 1997). This part of the learning cycle was typically short in duration (Bybee, 1997).

The exploration phase carried the same connotations for exploration as originally designed by Karplus and Atkin (Bybee, 1997). Karplus and Atkin (1962) concluded that the exploration phase was critical to provide common knowledge to all students since all students have different background knowledge and life experiences. Student exploration should be with concrete materials and hands-on. The goal of the exploration phase was to provide a common experience that the students and teacher could discuss to further scientific understanding in later phases (Atkin & Karplus, 1962). Teachers had the responsibility of providing the materials, observing and ensuring students were conducting the experiment correctly, and interacting with students while students were collecting data (Marek, 2008).

Physical experiences in the exploration phase were necessary (Bybee, 1997) and allowed the learner to move beyond initial observations to generalizations (Renner & Lawson, 1973). This generalization allowed the learner to think about the concept in other situations (Renner &Lawson, 1973). Piaget named this mental structure as logical-mathematical (Renner &Lawson, 1973). Furthermore, Renner and Lawson (1973) deduced from the work of Piaget that the exploratory experience must occur before abstract concepts are introduced. In studying the brain, Zull (2002) found that beginning with concrete experiences and examples was important in learning because it engages students' senses and allows for new neural networks to connect from existing networks. The exploration phase allowed learners, through the interactions of materials, to be able to understand and make abstract generalizations (Renner &Lawson, 1973).

Another key component of the exploration phase was the interaction with others (Bybee, 1997; Renner & Lawson, 1973). Cooperative groups, or cooperative learning, provided students with opportunities to recognize the perspective of others (Kelly, 2000). Students learned to listen to others, asked questions, and shared ideas when working together (Kelly, 2000; Renner & Lawson, 1973). The exploratory phase encouraged students to discuss with one another and built communication skills (Renner & Lawson, 1973). While students were discussing and sharing ideas in the exploration phase, the teacher circulated, asked questions, and guided students but not in a direct way (Atkin & Karplus, 1962; Bybee, 1997). It was also important that teachers provide students adequate time in the exploration phase before moving on to another phase (Withee & Lindell, 2006).

In the explanation phase, students were explaining what they discovered in the exploration phase (Withee & Lindell, 2006). Terms and definitions were expected to be discussed and clarified at this time (Bybee, 1997; Withee & Lindell, 2006). The teacher used this time to bring a connection with the students' thoughts from the explore phase to the focus concept (Bybee, 1997). Questioning by the teacher was a key part of the explanation phase and required caution on the part of the teacher not to tell the students the science concept (Marek, 2008). Questioning on the part of the teacher during explanation construction allowed the students to clarify and support their thinking as well as addressed any misconceptions presented in the initial explanation (Beyer & Davis, 2008). This phase closely aligned with the phase Karplus originally called invention and later renamed concept introduction (Bybee, 1997; Karplus 1976).

Once the students had an explanation for their experiences in the explore phase, the learning moved to the elaboration phase (Bybee, 1997). This phase followed what Karplus originally named discovery and later renamed concept application (Bybee, 1997; Karplus, 1976). In this phase students were applying or extending what they learned to a new situation (Atkin &

Karplus, 1962; Marek, 2008). Group interaction and group discussion were also important at this point of learning (Bybee, 1997). The goal of this phase was to move students from the physical experience to the logical-mathematical operation of thinking in which students can make generalizations about the concept (Bybee, 1997; Renner &Lawson, 1973). Likewise, Zull (2002) found that when learners tested, expanded, and manipulated ideas that true understanding of the concept developed.

Evaluation was the final phase but does not have to occur last (Bybee, 1997; Marek, 2008; NCTM, 2000). Evaluation could occur throughout the lesson (Bybee, 1997; Marek, 2008; NCTM, 2000). Evaluation provided feedback to teacher and student (Bybee, 1997; NCTM, 2000). The evaluation could be a way for teachers to determine students' level of conceptual knowledge, for students to assess their group knowledge, and for students to determine their own learning (Bybee, 1997; Withee & Lindell, 2006).

Although the learning cycle has its roots in the science field (Bybee, 1997; Atkin & Karplus, 1962), the tenets aligned closely with the national mathematics standards. Researchers provided examples of the learning cycle with mathematics (Marek & Cavallo, 1997; Marek et al., 2008; Simon, 1992). Marek (2008) described a science lesson in which students measured the circumference of objects to make a conclusion about the relationship of the circumference and diameter of circles. His description illustrated how the learning cycle could be used in mathematics teaching. Although his example was for a science lesson, it very easily could have been for a mathematics lesson on understanding area of circles. Similarly, Marek and Cavallo (1997) explained that the learning cycle could be used in mathematics for problem solving and provided examples of learning cycle lessons to teach measurement and geometry concepts.

The mathematics standards promoted students working together (NCTM, 2000), as recommended in the exploration and elaboration phases (Bybee, 1997). Using concrete tools and solving problems to develop a deep understanding of the concepts was core to the mathematics standards (NCTM, 2000) and aligned with the exploration, explanation, and elaboration phases of the learning cycle (Bybee, 1997). According to the mathematics standards, students generated their own mathematical questions (NCTM, 2000), a part of the engagement phase (Bybee, 1997), and students generated conclusions (NCTM, 2000), a part of the explanation phase (Bybee, 1997). The exploration, explanation, and elaboration phase supported a focus on thinking and reasoning skills that led to conjectures or arguments about the mathematics being examined (Bybee, 1997; NCTM, 2000).

The Learning Cycle: Elementary School through Higher Education

Swartz (1982) found that students should experience diverse methodologies that allowed students and teachers to explore and test scientific concepts. Components of inquiry were embedded in the learning cycle (Gee et al., 1996; Tracy, 1999; Withee & Lindell, 2006). Inquiry-based teaching involved the exploration of students around a central idea, formulation of questions, investigations to answer the questions, and reflection of learned ideas (Morrison, 2008; Tracy, 1999). Therefore, researchers recognized that the learning cycle provided a method for learners in any grade to explore and conduct investigations in mathematics or science (Gee et al., 1996; Tracy, 1999; Withee & Lindell, 2006).

Research was conducted with the learning cycle in the K-12 setting (Boddy, Watson, & Aubusson, 2003; Cardak, Dikmenli, & Saritas, 2008; Liu, Peng, Wu, & Lin, 2009). Researchers concluded that students using the learning cycle performed better than students in a traditional science classroom (Cardak et al., 2008; Ergin et al., 2008). Furthermore, Boddy et al. (2003)

found that the use of the 5E learning cycle promoted higher order thinking skills in primary age students. When working with a primary teacher in using inquiry-based teaching within the 5E model, the researcher and teacher showed students were more involved and more on task than they would have been in a traditional science lesson (Clark, 2003). Tracy (2003) designed a unit on volume that incorporated science and mathematics concepts using the learning cycle. She designed the unit to demonstrate how science and mathematics could be taught within the learning cycle framework. Schlenker, Blanke, and Mecca (2007) incorporated science and mathematics in an introductory chemistry unit with eighth graders that utilized the learning cycle. They found their students were excited about learning chemistry with the learning cycle approach. They also noted that the benefit of the learning cycle was that "the cycle could be entered at any point, and it is possible to loop back or ahead to another part of the cycle" (Schlenker et al., 2007, p. 86). Similarly, the 5E model had been used with high school students (Brown, Freidrichsen, & Mongler, 2008; Ksiazek et al., 2009). Brown et al. (2008) had high school students design miniecosystems based on the 5E model. The authors were surprised at the level of complexity in students' designs of the miniecosystems. In the culminating activity, students presented their findings of what occurred in the miniecosystems and asked and answered questions from other students. Ksiazek et al. (2009) designed a unit on seagrass for high school biology students that used the learning cycle. Students designed and conducted their own experiments to answer questions about seagrass and the effects of humans on seagrass. Their initial experiments led them to additional questions to answer about environmental issues. The teachers found that students were highly engaged, developed questions beyond the initial query, and demonstrated complexity and depth of scientific understanding of the topics (Brown et al., 2008; Ksiazek et al., 2009; Schlenker et al., 2007).

Research was conducted at the higher education level with the use of the learning cycle as well (Illinois Central College, 1979; Walker, McGill, Buikema, & Stevens, 2008). In response to students' low level of reasoning abilities, Illinois Central College designed freshman courses, English, mathematics, physics, history, social science and sociology, around the Karplus model of the learning cycle (1979) (Illinois Central College, 1979). Students who participated in the Development of Operational Reasoning Skills (DOORS) Project at Illinois Central indicated that the classes held more meaning for them (Illinois Central College, 1979). Walker et al. (2008) compared college sophomore students in a traditional microbiology laboratory and a laboratory that used the 5E model with embedded inquiry. They found that the students in the inquiry-based lab were better able to answer test questions on the lab content.

Researchers examined preservice teachers in regard to inquiry-based teaching (Haefner & Zembal-Saul, 2004; Morrison, 2008; Park Rogers & Abel, 2008). Haefner and Zembal-Saul (2004) studied eleven elementary preservice teachers' development in a life sciences course. They found that the inquiry-based course helped preservice teachers confront misconceptions of science teaching and supported preservice teachers' understanding of science. Stamp and O'Brien (2005) worked with graduate students and in-service elementary teachers to develop science curricular units using the 5E learning cycle model that aligned with the state standards. They found that the teachers in the study became more skillful in their science teaching having received professional development on teaching with the 5E model. At the college level, Withee and Lindell (2006) studied five methods instructors. They found that the instructors supported inquiry based teaching but found some difficulties in using the 5E model. Difficulties included students reluctant to move out of the explore stage, difficulty in separating the stages, and that one model does not always meet the instructional needs of the lesson.

Researchers developed tests to determine preservice teachers' understandings of the learning cycle during methods class (Marek, et al., 2008; Odom & Settlage, 1996). Odom and Settlage (1996) developed a test to determine preservice teachers understanding of the learning cycle called the Learning Cycle Test (LCT). Lindgren and Bleicher (2005) examined how preservice teachers learned the learning cycle. In the science methods class, the researchers conducted experiments using the three historical phases of the learning cycle (Karplus, 1976): exploration, concept introduction, and concept application. The LCT (Odom & Settlage, 1996) was administered and the beginning and end of the course. Results indicated varied conceptions of the learning cycle even after receiving instruction on the learning cycle and lessons modeled with the learning cycle. To provide insight into students' thinking about the learning cycle, Lindgren and Bleicher (2005), in addition to the LCT, also used reflective journals kept by the students throughout the course and focus group discussions provided. Data indicated that students had a difficult time conceptually changing the ideas about teaching science (Lindgren & Bleicher, 2008). Some students embraced the learning cycle due to dissatisfaction of the way they experienced science in school (Lindgren & Bleicher, 2005). Preservice teachers' understanding of the learning cycle improved with the continued exposure of the learning cycle in methods class (Lindgren & Bleicher, 2008). Marek et al. (2008) modified the Learning Cycle Test (LCT) by adding questions that focused on the teacher's role. He named the two-tiered test Understanding the Learning Cycle (ULC). Instructors who gave the ULC indicated they liked it better than the LCT and felt it provided a more accurate indication of preservice teachers' conceptions.

The learning cycle was an inquiry-embedded model that supported conceptual change of thinking (Withee & Lindell, 2006) in which the learners replaced old ideas with new ideas

(Posner et al., 1982). Similar to the findings of Lindgren & Bleicher (2005), Gee et al. (1996) found that elementary education majors, after experiencing the learning cycle in content courses and methods courses, were still not completely committed to the use of the learning cycle in their own teaching. They speculated that preservice teachers may have difficulty translating the theory and experiences of the methods class into their teaching practice (Gee et al., 1996). However, Lindgren and Bleicher (2008) noticed students, who had negative science experiences or were dissatisfied with the way they were taught, embraced the learning cycle approach. This indicated multiple factors methods instructors have to consider when using the learning cycle approach: preservice teachers' prior experiences in science, flexibility in thinking about teaching science in a different way, and learning modules to help breech the barriers.

Little research has been conducted with elementary preservice teachers with mathematics and the use of the learning cycle (Lindgren & Bleicher, 2005; Marek et al., 2008). The research that exists on preservice teachers and the learning cycle focused primarily on science (Lindgren & Bleicher, 2005; Marek et al., 2008; Urey & Calik, 2008). Urey and Calik (2008) determined that the use of the learning cycle promoted conceptual change in pre-service science teachers' understanding of cells. Additionally, Marek (2008) provided examples of the learning cycle in science and mathematics. He provided detailed descriptions of how teachers could develop and implement the learning cycle. He also gave examples of a learning cycle lesson on understanding diameter and circumference of circles. Simon (1992) proposed that learning cycles existed in mathematics teacher education programs as preservice teachers learned new ways to think about mathematics and applied that knowledge to the teaching of students.

Conclusion

As previously mentioned, elementary preservice teacher education programs often were compartmentalized based on subject and further divided into content courses and methods courses (Quinn, 1997). Other researchers focused on the integration of science and mathematics as subjects (Berlin & White, 1991; Frykholm & Glassen, 2005; Lonning & DeFranco, 1994, 1997; Lonning, DeFranco, & Weinland, 1998; Stuessy, 1993; Steussy & Naizer, 1996). However, this research presented an opportunity to examine conceptions of common approaches between science and mathematics teaching, and how preservice teachers put their knowledge into practice. Since many of today's preservice teachers lacked a model of standards-based reform teaching (CBMS, 2001), approaching teacher development from a perspective of commonalties in mathematics and science teaching could help elementary preservice teachers better understand how to teach mathematics and science. Researchers called for more research that uses new innovative teaching techniques (Manouchehri, 1997). Furthermore, Manouchehri (1997) called for researchers to conduct long term studies on change of preservice teachers and how this change was exhibited in mathematics teaching practices.

CHAPTER 3: METHODOLOGY

Introduction to the Study

The purpose of this research was to examine elementary preservice teachers' mathematics and science thinking and practice in relation to conceptions of pedagogy, tools for conceptual development, and processes for meaningful learning while in a joint science and mathematics methods class and subsequent internship experience. The research questions of this study were: (1) What are preservice teachers' conceptions of tools for conceptual development, processes for meaningful learning, and pedagogical approaches prior to and after taking the mathematics-science methods courses? (2) What changes, if any, in development of knowledge and understanding of the common approaches between mathematics and science occurred while taking the mathematics-science methods courses? (3) How did preservice teachers put into practice during student teaching their thinking from the methods courses on tools for conceptual development, processes for meaningful learning, and pedagogical approaches to mathematics teaching?

The purpose of this project was to examine elementary preservice teachers' thinking and practice on common approaches mathematics and science as they moved through co-requisite science and mathematics methods courses to student teaching. This study used a qualitative design (Creswell, 1988; Merriam, 1998). The study took place in two phases. Phase I occurred during the participants' science and mathematics methods classes. Phase II occurred during the participants' student teaching experience. Data sources for Phase I included an open-ended pre-test (see Appendix A in overall appendix section), open-ended post-test (see Appendix B in overall appendix section), and weekly blogs (see Appendix C in overall appendix section). Data sources for Phase II included written observations of preservice teachers teaching mathematics taken as field notes during 5 to 6 observations, follow-up interviews with preservice teachers after the observation (see Appendix D in overall appendix section), and a final reflection (see Appendix E in overall appendix section). Information from observations, interviews, and blog responses were linked through a coding process.

Research Paradigm

This research is based on a constructivist paradigm. At the heart of constructivism is the notion that a learner constructs knowledge (Beeth, Hennesey, & Zeitsman, 1996; Piaget, 1976). Since each individual experiences the world in different ways, then realities are different for each person (Beeth et al. 1996; Denzin & Lincoln, 2003). Therefore, researchers with a constructivist paradigm recognize relativist ontology: that "there are multiple realities" (Denzin & Lincoln, 2003, p. 35). With this recognition of multiple realities comes the acknowledgement of a person only knowing their own reality and researchers attempting to understand someone else's reality from the view of their own (Beeth et al., 1996). Constructivism recognizes multiple ways of thinking and freedom in thinking and understanding in different ways (Beeth et al., 1996).

A constructivist paradigm also assumes a subjectivist epistemology: that the "knower and responder cocreate understandings" (Denzin & Lincoln, 2003, p. 35). With this cocreation of understanding is the supposition that the teacher will create a learning environment conducive to learning. Methodological procedures focus on the natural world. Pattern theories or grounded theories are used to communicate the results of a constructivist paradigm (Denzin & Lincoln, 2003). This product is often in the form of case studies or narratives (Hatch, 2002). The voice of the participant becomes an important part of the written account (Hatch, 2002).

Constructivist Grounded Theory Methodology

This research used a constructivist grounded theory methodology (Charmaz, 2005). Glaser and Strauss (1967) are credited with the seminal work on grounded theory. A theory "explains or predicts something" (p. 31). In their work they define grounded theory as "the discovery of theory from data" rather than using data to verify a theory (p. 1). They concluded that since the theory was determined based on the data that the theory would be long lasting. Furthermore, they argued that the process for generating the theory is just as important as the theory itself.

Glaser and Strauss (1967) described comparative analysis as a means for generating theory. Comparative analysis can be used to determine accuracy of evidence, make empirical generalizations, specify a concept of analysis, verify theory, or generate theory. When determining accuracy of evidence, comparative analysis begins with a conceptual category being assigned to a piece of data. This conceptual category is derived from a set of data and can be applied to other similar data sets. When comparing to other data sets, limits to the concept are determined to make empirical generalizations (Glaser & Strauss, 1967). Negative cases that stand out or positive instances that support the research are used to verify the theory that is being generated. With grounded theory, concepts emerge from the data to generate substantive theory. Substantive theory leads to formal grounded theory (Glaser & Strauss, 1967).

There are two elements of theory: categories and properties, and hypotheses. Glaser and Strauss (1967) defined a category as "a conceptual element of the theory" (p. 36). Within each category are properties. "A property, in turn, is a conceptual aspect or element of a category" (Glaser & Strauss, 1967, p. 36). Although there are different approaches to analyzing qualitative data, Glaser and Strauss (1967) recommended the constant comparative method. The constant comparative method combines coding and analyses of the codes together (Glaser & Strauss, 1967). This allows the researcher to stay close to the data to ascertain the dimensions and properties of the data (Glaser & Strauss, 1967).

The constant comparative method involves four stages (Glaser & Strauss, 1967). Although one stage leads into the next, the previous stages are still taken into account (Glaser & Strauss, 1967). When reading through the information, the researcher designated a word or phrase that represents the meaning of each part of the data (Saldana, 2009). This process of designation is called coding and is the first stage of the constant comparative method (Glaser & Strauss, 1967). "To codify is to arrange things in a systematic order, to make something part of a system or classification, to categorize" (Saldana, 2009, p. 8). Codes were derived from a phrase from the participants in the study or as an explanation of the phenomena by the researcher (Glaser & Strauss, 1967; Saldana, 2009). As the coding continued, comparisons had to be made to same and different groups within the data (Glaser & Strauss, 1967). Coding continued until saturation had been reached (Glaser & Strauss, 1967). Once saturation had been reached the second stage of the constant comparative method began (Glaser & Strauss, 1967). In this stage comparisons were no longer made from event to event but from event to properties of events (Glaser & Strauss, 1967). Comparisons of events and properties often led to a beginning conception of the theory (Glaser &Strauss, 1967).

Now that a theory was developing the researcher began to narrow the information (Glaser & Strauss, 1967). This is the third phase of the constant comparative method (Glaser & Strauss, 1967). This narrowing process included eliminating irrelevant properties as well as unifying concepts to create a reduction of concepts that helps to clarify the theory (Glaser & Strauss, 1967). Glaser and Strauss (1967) term this part of the process as theoretical saturation. At this point if new categories emerged, then the researcher continued with the new categories and returned back to the beginning of the data with the new categories, if necessary (Glaser & Strauss, 1967). The final stage of the constant comparative method involved actually writing the theory (Glaser & Strauss, 1967). Using the data, codes, and developed theory, the researcher wrote a framework outlining the theory. The researcher used specific incidents to give illustration to the points being made about the theory (Glaser & Strauss, 1967).

Charmaz (2005) determined that grounded theories were being used beyond the original scope of Glaser and Strauss (1967). Barney G. Glaser had an extensive background in quantitative methods (Charmaz, 2006). Anselm L. Strauss, on the other hand, had experiences with qualitative work in the Chicago School (Charmaz, 2006; Denzin & Lincoln, 2005). Unlike grounded theory portrayed by Glaser and Strauss (1967), constructivist grounded theory does not take an objective stance (Charmaz, 2005). It assumes the researcher brings experiences and bias into the data collection and analysis and cannot be separated from that methodological perspective (Charmaz, 2005). Therefore, interpretations of the data are not objective but rather interpreted findings (Charmaz, 2005).

Researcher as Part of the Research Process

The researcher brought a framework of beliefs that could not be separated from the research process (Denzin & Lincoln, 2003). "All research is interpretive; it is guided by a set of beliefs and feelings about the world and how it should be understood and studied" (Denzin & Lincoln, 2003, p. 33). The researcher was a former elementary classroom teacher. As a classroom teacher, the researcher mentored preservice teachers in methods lab placements as well as supervised interns. The researcher also served as the school teacher leader and district teacher leader for mathematics. Working under a multi-year NSF grant, TEAM-Math, the researcher had experience training inservice elementary teachers on research-based methods for teaching mathematics. Similarly, the researcher also had experience teaching previous cohorts of preservice teachers the mathematics methods course using researched based materials. However, the researcher used the learning cycle in the mathematics methods course for the first time with the cohort in this study.

The researcher's perspective impacted the way observations were made, interpretations of findings, and how concepts were integrated (Denzin & Lincoln, 2003; Merriam, 1998). Those experiences provided the researcher with the facility to interpret the phenomenon and allowed the researcher to adapt to situations being studied (Merriam, 1998). For example, the researcher became familiar with the investigation materials for teaching mathematics as a classroom teacher and school teacher leader. When the researcher observed lessons in which the preservice teachers used those materials, she was aware of instances in which they altered the intent of the lessons or expanded the lessons. The researcher was unaware of the type of teaching she would see when going into the classrooms of the student teachers. However, she was aware of the types of materials and the training the cooperating teachers in the schools had received. The researcher was able to bring those resources to the attention of the student teachers to help them improve their practice. Therefore, the researcher's experiences, culture, and community played a part of the research process (Denzin & Lincoln, 2003).

Phase I of the study took place in the classroom and in an on-line environment. Participants completed the open-ended pre-test and the open-ended post-test in the methods class on campus. For both science and mathematics portions of the methods class, participants completed science and mathematics modules using the learning cycle approach. Phase II of the study took place in the natural setting of what was being studied: elementary preservice teachers in learning environments practicing and learning how to teach during student teaching (Bogdan & Biklen, 1982; Hatch, 2002; Merriam, 1998). The settings varied based on where the preservice teachers were placed. The researcher studied the preservice teachers in the natural setting and made an attempt to cause as little disruption as possible when in the varying learning environments (Merriam, 1998). Being in the environment allowed the researcher to acquire information firsthand, learn about the daily routines, and become familiar with the context of the learning environment for each preservice teacher involved in the study (Bogdan & Biklen, 1982; Glaser & Strauss, 1967; Hatch, 2002; Marshall & Rossman, 1995; Merriam, 1998). Furthermore, a test or written survey would not have provided an entire picture of the preservice teachers' practice.

The researcher served as the primary investigator who attempted to record the phenomena, person, and/or interactions being studied (Hatch, 2002; Lancy, 1995). The researcher recorded observations and took notes in the field or field notes (Hatch, 2002). "Qualitative researchers build toward theory from observations and intuitive understandings gained in the field" (Merriam, 198, p. 7). The researcher served as an instrument for data collection since the researcher's sense-making influenced what the researcher distinguished as important in the setting (Hatch, 2002; Merriam, 2009). Moreover, the data that was collected was limited by not only the constraints and limitations of the setting, but by the personal lens of the researcher collecting the information (Denzin & Lincoln, 2003; Merriam, 1998). In essence, due to human factors, "mistakes are made, opportunities are missed, and personal biases interfere" (Merriam, 1998, p. 20). Thus, in order for the researcher to gain insight into what is being studied extended time in the field was a necessity (Hatch, 2002).

Design and Research Methods

Case Study Approach

For this study a case study approach was used (Hatch, 2002; Merriam, 1998; Stake, 2005) based on a constructivist grounded theory perspective (Charmaz, 2005), and used a grounded theory approach to analysis (Glaser & Strauss, 1967). A case study is an in-depth study of a real life situation with specific boundaries (Hatch, 2002; Merriam, 1998; Yin, 2009). A case study is used when aspects of a phenomenon need to be studied up close (Merriam, 1998; Yin, 2009). Since case studies involve examinations of real life, then field work is a necessary component (Merriam, 1998; Yin, 2009). The human factor of the researcher allowed the researcher to be flexible in the data collection process if unforeseen events occurred (Merriam, 1998). A couple of time schedule changes and special assemblies altered observation times, shortened the length of the teaching episode, and altered when the follow-up interview could take place. The researcher had to be sensitive in the data collection process with note taking, interview style, and in data analysis (Merriam, 1998). Sensitivity in data collection meant the researcher was careful to record as much as possible about the teaching episode in order to keep the written observation as true to the teaching episode. The students in the class were not recorded by name as to protect their identity. Recognizing the hard work and effort student teachers put into their work, the researcher approached the follow-up discussions in a diplomatic manner so as not to discourage the student teacher. The human factor also meant that bias was inherent in the observations and analyses due to the fact that a human collected, investigated, and made determinations based on a human's knowledge (Merriam, 1998).

Data collection of a case study typically involves many different types of information (Yin, 2009). Multiple sources means that the similarities and differences within the information are identified (Yin, 2009). This process of examining the converging information from the multiple sources is known as triangulation (Yin, 2009). Specifically, this study used a multiple case design in which multiple cases were examined (Merriam, 1998; Yin, 2009). Furthermore, evidence in case studies may take the form of observations, interviews, documents, artifacts, or records (Merriam, 1998; Yin, 2009).

In order to try to determine preservice teachers' conceptions of pedagogical approaches, tools for conceptual development, and processes for meaningful learning, case studies were the best approach. The pre-test on the first day of class established the preservice teachers' conceptions of tools, processes, and approaches for science and mathematics teaching. The weekly blogs presented a progression of thinking from science methods to mathematics methods. The post-test at the end represented their culminating knowledge about tools, processes, and approaches for science and mathematics teaching. All of these documents for each person became the evidence for each case. Case studies enabled the researcher to see the progression of thought with individuals and compare that with the thoughts of other participants. For Phase II of the study case studies allowed the researcher to observe the preservice teachers in their teaching environment (Merriam, 1998; Yin, 2009). Furthermore, the researcher was able to conduct follow-up interviews to gain insight into the preservice teachers' choices and understanding about practices for teaching mathematics (Merriam, 1998; Yin, 2009).

Participants

Participants of qualitative research are often a purposeful sample rather than a random sample (Merriam, 1998). This study used a purposeful selection of preservice teachers. Phase I of the study involved 22 preservice elementary teachers in a 10 week semester course which required dual enrollment in a science methods class and a mathematics methods class. Preservice teachers in the elementary education program at the large southeastern university were organized into cohorts prior to taking methods courses. Methods courses occurred before internship. Methods courses focused on practice, theory, and reflection (Hill, 1997). The students in the science methods class were the same students in the mathematics methods class. The course was divided into two five-week segments. The first five weeks were devoted to science methods. The university assigned professor taught the science methods portion of the class. During those five weeks participants attended class on campus as well as attended lab sites. In the lab sites participants taught science lessons to students in grades K-5. The second five weeks of the semester focused on mathematics. The researcher of this study was the instructor of the mathematics methods class. Preservice teachers worked in a different lab site with K-5 students during the second half of the semester teaching mathematics.

Preservice teachers attended class on campus as well as worked with students in lab sites. Although the science lab sites were different from the mathematics lab sites, practice teaching children provided an opportunity for new teachers to learn how to teach as well as validate new practices being put into place (Hill, 1997). Due to the nature of the classes as a methods class, preservice teachers learned pedagogy, observed modeling of science and mathematics, peer-taught lessons, and then practiced their teaching skills with students in the field. Howitt (2007) found that preservice teachers identified that science activities that could be used with students in the field helped build the confidence of the preservice teachers in the teaching of science.

The science methods course and the mathematics methods course were jointly planned by the researcher, who was the mathematics methods instructor, and the science methods professor to have commonalities between the designs of the sections. The 5-E learning cycle with inquiry embedded instruction (Marek & Cavallo, 1997; Withee & Lindell, 2006), national standards for science (NRC, 1996) and national standards for mathematics (NCTM, 2000) were foci of the classes. The methods classes focused on connecting content and pedagogy (Molina et al., 1997). Content in the on-campus portion of class focused on inquiry-based materials. For science methods class, those materials included science kits that were developed from an inquiry perspective with the learning cycle as the framework. Science lessons in the on-campus portion of the science class included lessons from *Full Option Science System* (Foss) (Lawrence Hall of Science, 2003), *Science Technology for Children* (STC) (National Science Resources Center, 2003), and *Insights* (EDC Science Education, 2003). For the mathematics portion of class, materials consisted of materials from NCTM and the *Investigations* curriculum (Pearson Education, 2007). In both classes preservice teachers participated in investigations and experiments, discussions, and readings (Chick, 2007; Heywood, 2007; Hill, 1997). The learning cycle was used as a common approach in the science methods and carried into mathematics methods. Preservice teachers were required to design their lessons for both science and mathematics field experiences using the learning cycle as a framework.

Since the fragmented knowledge of preservice teachers is well documented (Ball, 1988; Heywood, 2007; Manouchehri, 1997) along with an instrumental understanding of the subject (Heywood, 2007; Hill, 1997), experiments, discussions, and readings were selected to challenge preservice teachers' conceptions of science and mathematics to promote conceptual change (Green et al., 2008; Heywood, 2007). Howitt (2007) found that modeling by the teacher educator to be influential in pedagogical content knowledge of the preservice teachers. In both methods classes, modeling was used to help preservice teachers gain insight into the material for content knowledge as well as gain insight into the how of teaching the content. Green et al. (2008) found that focusing on manipulative based tasks that allowed students to explore and address misconceptions of mathematics were very beneficial to the preservice teachers. Preservice teachers, in a study conducted by Hatton (2008), felt that the class investigations aided them in their growth and development. Manipulatives and tools for conceptual development were similarly used in both classes during investigations to foster development of content knowledge and pedagogical content knowledge. In science methods class, one of the modules completed focused on earth science. Preservice teachers examined rocks and completed a series of inquiries with the rocks following the learning cycle approach. In the mathematics methods class, preservice teachers used three-dimensional solids and rice in one module that focused on volume of three-dimensional figures. Preservice teachers used the rice to determine the volume of figures and make comparisons between figures. From their findings they determined the relationship among the volume for three-dimensional figures. Specifically, in both methods classes preservice teachers engaged in group discussion, produced representations of thinking, conducted investigations to test phenomena, were held accountable within a peer group, and reflected on mathematical and scientific justifications (Gresham, 2007; Heywood, 2007; NCTM, 2000). During the volume module preservice teachers worked in groups, recorded their information in a journal, and presented the information to the class. Similarly, with the rock module, participants completed a series of tasks intended to expand their understanding of rocks, as well as provide a level of comfort with such tasks. Science notebooks were used by the preservice teachers to record data and their thinking as they completed the modules. Preservice teachers shared their understandings of the rock inquires within their groups and with the class.

“Mathematics anxiety is a feeling of helplessness, tension, or panic when asked to perform mathematics operations or problems” (Gresham, 2007, p. 182). Gresham (2007) found that the use of manipulative with elementary preservice teachers in a methods course aided the preservice teachers in reducing mathematics anxiety. With the documentation of anxiety of mathematics and avoidance of science (Appleton & Kindt, 1999; Howitt, 2007; Sanger, 2006), group investigations and discussions were also conducted to provide an opportunity for students to experience mathematics and science at their own pace and possibly with less anxiety since they did not have to do it individually (Gresham, 2007; Howitt, 2007).

Since the researcher served as one of the methods instructors for Phase I of the study, the participants were invited to participate at the end of the semester. Twenty-two of the twenty-five students agreed to participate in the study. A neutral third-party administered the consent forms and released them to the researcher at the beginning of the following semester after all grades had been posted. Since the researcher did not serve in any supervisory role for the internship, the researcher presented the invitation to participate in Phase II of the study which would take place during their student teaching. Only participants who had consented for Phase I of the study were invited to participate in Phase II of the study. Five preservice teachers who had participated in Phase I agreed to participate in Phase II. The researcher sent e-mail requests to obtain permission to observe interns to superintendents of the school systems. Once the participants agreed to participate, the researcher also sent e-mails to the principals of the individual schools in which the participants were completing their student teaching to obtain permission to observe.

Data sources

The study was conducted in two phases. Phase I occurred while the preservice teachers were in the mathematics and science methods classes. Phase II occurred while the preservice teachers were in their internship. In qualitative research data gathering instruments vary (Lancy, 1993; Marshall & Rossman, 1995; Yin, 2009). For this study data gathering instruments included observations, interviews, field notes, and written artifacts such as pre-tests, post-tests, blogs, and final reflections (Lancy, 1993; Marshall & Rossman, 1995; Yin, 2009). Merriam (1998) recommended that researchers chose data collection instruments that are "sensitive to the underlying meaning" (p. 1) of the research.

Phase II of the study also used direct observation (Yin, 2009). Direct observation means the researcher observed the participants in the field; the field being the place of occurrence for the phenomena (Yin, 2009). Qualitative research relies on observation of behavior since it indicates underlying values and beliefs (Marshall & Rossman, 1995). Observations included direct notations of what was observed and heard as well as notes taken after the fact by the researcher (Lancy, 1993; Marshall & Rossman, 1995). Field interviews followed the field observations (Yin, 2009).

The study consisted of multiple data sources during both phases (Merriam, 1998; Patton, 2002; Yin, 2009). Phase I data sources consisted of an open-ended pre-test (see Appendix A in overall appendix section), an open-ended post-test (see Appendix B in overall appendix section), and weekly blogs (see Appendix C in overall appendix section). Participants completed an open-ended pre-test at the beginning of the science methods course. On the last day of the semester in the mathematics methods course they completed the open-ended post-test. The pre-test questions consisted of knowledge questions intended to elicit information from the participants about their knowledge of common approaches to teaching mathematics and science (Patton, 2002). The post-test questions consisted of knowledge questions about similarities in mathematics and science, questions of common practices to mathematics and science, as well as opinion questions on how the participants thought about their teaching experiences (Patton, 2002).

After examining preservice teachers' learning of the learning cycle, Lindgren and Bleicher (2005) found discussion and journal writing were key components of students gaining understanding of the learning cycle. In order to document reflection and change of thinking, computer-mediated communication (CMC) in the form of weekly weblogs (blogs) provided a venue for participants to describe experiences, past and present, and reflection on science and mathematics teaching (Heywood, 2007; Howitt, 2007; Lindgren & Bleicher, 2005). Online postings were required each week (Hatton, 2008). Blogs provided an opportunity for preservice teachers to reflect upon their experiences in methods class and experiences in the field practice teaching as a means to help them improve their learning and teaching (Howitt, 2007). Blogs were visible to students and the instructors of the courses who were asked to reply to other students' blogs to provide a venue for discussion. Some students are reticent to speak up in class but may feel more freedom to express themselves through computer mediated communication (Wiegel & Bell, 1996). The blog offered the students the opportunity to share and discuss their thoughts and ideas about the learning and teaching of mathematics and science. Blog questions asked in the science methods portion in the first five weeks were revisited in the mathematics methods portion the second five weeks.

Phase II of the study consisted of five of the Phase I participants and occurred during their student teaching experience which occurred the final semester of their senior year. At the end of the study only two of the five who agreed to participate were included. Two of the participants who agreed to participate in the study were not viable cases because they were placed in classrooms in which reform-based methods of instruction were not allowed. The other participant who agreed to participate in the study was placed in a school that was geographically too far from the researcher to complete multiple observations. The two participants, that were included in the study, were placed in schools with teachers who had participated in state science and math initiatives. The participants had access to materials and tools to develop and teach reform-based mathematics lessons. Finally, the cooperating teachers gave them freedom in designing, planning, and implementing lessons for the two-week full-time teaching period. Both participants in the study were also included because they presented two different views of teaching and learning mathematics based on their responses during the methods classes. Data from Phase II consisted of teaching observations, written as field notes, follow-up interviews, lesson plans, and an open-ended final summation (Merriam, 1998). Lesson plans were a weakness of the data collection. The lesson plans, when given to the researcher, were very sparse and contained the bare minimum such as objective and page numbers.

However, observations and follow-up conversations about the observed teaching lesson yielded more information about the thoughts of the preservice teachers. Observations consisted of detailed descriptions of preservice teachers teaching mathematics (Merriam, 1998; Patton, 2002). Observations have an inherent constraint in that the presence of the observer may change the actions of the one being observed (Patton, 2002). Observations, written as field notes, were taken as participants were teaching their lessons (Merriam, 1998; Patton, 2002; Yin, 2009). Field notes contained the actual descriptions of events and what occurred in the teaching episode (Lancy, 1993; Merriam, 1998; Patton, 2002).

Since observations alone cannot provide enough information about the thinking of the participants, interviews were also conducted (Merriam, 1998; Patton, 2002; Posner & Gertzog, 1982; Yin, 2009). Interviews were another data gathering instrument used in this research (Lancy, 1993; Marshall & Rossman, 1995; Merriam, 1998; Yin, 2009). The clinical interview, which takes its roots from the work of French psychologist Jean Piaget, is a face-to-face interview with an interviewer and an interviewee (Posner & Gertzog, 1982). Interviews allowed the participants to express their personal thoughts and feelings on the phenomena being studied

(Lancy, 1993; Patton, 2002). “One’s goal in this type of interviewing is to obtain information, but also to remove any constraints on the interviewee’s responses so that her conceptualization of the phenomena emerges rather than having her fit her views into the investigator’s framework” (Lancy, 1993, p. 17). Of the varying types of interviews, Phase II of the study used the general open-ended question interview (Patton, 2002; Posner & Gertzog, 1982). Interviews were framed around open-ended questions (See Appendix D in overall appendix) meant to illicit participant’s thinking about teaching practices for mathematics (Marshall & Rossman, 1995; Merriam, 1998). Interview questions were framed similarly to questions in Phase I (See Appendix A in overall appendix) to provide a continuum of thinking from methods course to student teaching experience. Interviews were flexible to allow for articulation of thoughts by the interviewee (Patton, 2002; Posner & Gertzog, 1982; Yin, 2009). Additional questions were asked in order to gain clarification from the participant (Merriam, 1998; Patton, 2002; Posner & Gertzog, 1982).

Finally, a follow-up open-ended assessment (See Appendix E in overall appendix) was used as another data source. This final reflection consisted of questions similar to questions posed in Phase I (See Appendix B in overall appendix) of the study. Questions focused on tools for conceptual development, approaches to teaching mathematics, and processes for meaningful learning.

Data Management

The information was managed in several ways. Once the investigator had the consent letters from Phase I she created a code list. Each consenting participant was designated with a name and number. The first participant on the list was designated as Person 1. The second person was designated as Person 2 and so on. She then logged into the secure blog site, converted all of the files for the consenting participants into text files, deleted any names, and replaced the names with the code name. Participants were designated as Person 1, Person 2, and Person 3. etc. The blog for week one was then titled Person 1 Blog 1. The pre-test and post-test had been hand written by the participants. The researcher typed all of the pre-tests and post-tests for the consenting participants, deleting any names, and replaced with the name and number. All of these were placed in a file labeled for each participant. This process continued for all 22 participants.

Since the researcher was not a supervisor during the participants' internship experience, she passed out the consent forms to the preservice teachers for Phase II of the study. All information for Phase II was treated the same way as Phase 1. Each document was labeled and coded as the participant's same code name from Phase 1. Files were created with all of the documents for each of the participants for Phase II. The code name list was destroyed as well as all original hand written documents. All documents remaining were only designated by the code name.

Data Analysis: Phase I

For Phase I there were twenty-two cases to code. For Phase II there were two cases to code. First level coding occurred with each blog, pre-test, post-test, interview, and observation field notes (Merriam, 1998). Merriam (1998) called this initial coding as category construction. Keeping in mind the research questions the researcher attempted to create categories that would "reflect the purpose of the research" (Merriam, 1998, p. 183). Pieces of information that were striking to the researcher were noted in Person 1 pre-test (Merriam, 1998). Categories were determined based on words or phrases from the participants, conclusions from the researcher, or connections to existing research (Glaser & Strauss, 1967; Merriam, 1998). For example, when Person 1 on the pre-test described students in the field placement taking apart machines to understand how the machines were designed (Phase I, 2008) the researcher coded based on the phrasing of the respondent as “took apart machines for understanding”. Then the first pre-test was read through again for the case to determine if commonalities existed that could group some of the items together or if other generalizations became apparent (Merriam, 1998). After rereading the Person 1 pre-test the researcher made a second code next to the code “Teacher will need to know what will happen” as “teacher control”. Then the first blog for Case 1 was read through for category construction. New categories were designated based on new information: “need for fun”, “benefits”, and “traditional approach criticism” (Phase I, Person 1-Blog 1, 2008). Then the pre-test categories and the blog categories were compared to generate any new categories. After rereading the codes for Person 1 pre-test and Person1-blog 1, there weren’t any codes the researcher wanted to add or change. The researcher then went on to code Person 1-blog2. The respondent indicated that the learning cycle were five steps to follow and the researcher coded this as “LC as steps”. The researcher then reread for Person 1 the pre-test, blog 1, and blog 2. The researcher saw a thread of the preservice mentioning hands-on. The researcher made a list of the codes from the first three data sets (Merriam, 1998). From the list of initial codes the researcher referred to the research questions (Merriam, 1998). This process continued for all 22 cases.

The research questions dealt with five main areas: tools for conceptual development (designated with a T in the coding process), processes for meaningful learning (designated with PFML), pedagogical approaches (designated with PA), and more specifically common approaches between mathematics and science (designated with CA). Since the learning cycle was used as a common approach in the science and mathematics methods course, then aspects of the learning cycle were designated with an LC. Preservice teachers also added many personal experiences about learning mathematics and science. A category was designated for personal experience (PE) in order to differentiate it from their current practice (see Appendix F for coding guide).

The researcher added the prefixes to the initial codes. For example, on Person 1-pretest, the researcher noted that the respondent indicated group activities and hands-on activities as being a common to teaching mathematics and science. The researcher coded as “CA-group activities”. For the next data set the researcher used both the category designations and codes. For codes from the post-test the researcher noted post-test at the end of the code. At the end of the coding for each person the researcher again read through all of the codes and made a memo for thoughts, ideas, questions, or potential themes (Charmaz, 2006; Merriam, 1998). This process constant comparison continued for each set of data for each case (Charmaz, 2006; Glaser & Strauss, 1967; Merriam, 1998).

A chart (See Appendix G in overall appendix for sample) was made for each participant that included the T, P, PA, CA, LC, and PE coding of labeling. Codes were placed in the chart for each person in chronological order with a source code at the end. “Pre” and “Post” were source codes for the pre-test and post-test. The letter B and a number were used for blog source codes. For example on Person 1 under T, “Took apart machine in FEP b3, Promoted fun b3”.

Based on the research questions the researcher examined the code list for each person based on each category. Based on the codes for tools the researcher refined the code list (See Appendix H in overall appendix for sample). For example, the researcher recorded for Person 1“Moved from seeing tools in science as teacher controlled experiments to students understanding the phenomena for themselves” (Person 1, Coding level 2 Tools). This continued for each participant for the tools, processes, pedagogical approaches and commonalities of mathematics and science. Once all of the coding had been completed, then patterns were generated within same cases and across different cases for both phases (Glaser & Strauss, 1967; Merriam, 1998).

After all of the level two coding was completed the researcher examined data across the cases to make further generalizations. These generalizations were organized into the themes for each category (See Appendix I in overall appendix for sample). Themes were organized based on initial conceptions and end conceptions. For example, three themes stood out for participants' initial conceptions of the use of tools in science: saw tools in a traditional role, expanded view of tools, or more progressive view of tools. The researcher examined the development of participants' conceptions of tools to determine how their thinking about the use of tools in science had changed over the course of the semester. This organization of themes continued for processes, pedagogical approaches, and common approaches of mathematics and science. Traditional ideas and progressive ideas were noted for each area. Traditional concepts were those that mirrored traditional mathematics and science instruction in which instruction and lesson design focus on fact learning rather than conceptual learning. This includes the use of tools for teacher directed lessons that focus in mathematics on getting right answers and in science on teacher led experiments or following a science textbook.

Based on their responses on the pre-test, participants' conceptions of tools were categorized into three categories: traditional view of tools, expanded view of tools, or progressive view of tools. Traditional views of tools followed traditional methods of science instruction and were indicated by teachers conducting experiments for the students to observe, textbook learning, or science projects. Responses that had a mixture of students conducting experiments, worksheets, textbook learning, and students looking at pictures were classified as expanded view of tools for science. The progressive category included comments about students exploring in nature, physical knowledge activities, or students completing hands-on tasks for conceptual development.

Categories for conceptions of tools in mathematics were categorized the same as for science: traditional role of tools, expanded view of tools, or progressive view of tool. Initial responses in which tools were for computation or facts were placed in the traditional view. Responses in which tools were used for primary concepts such as shapes, money, or counting were included in the expanded view. Progressive views of tools in mathematics included comments about tools for hands-on learning or for understanding the concept.

In examining how preservice teachers conceived of processes for learning, their responses fell into three distinct categories. Processes for learning were categorized as traditional, expanded, or progressive. Processes in which students focused on students finding answers were categorized as traditional. Preservice teachers in this category saw experiments as a means for students to find predetermined outcomes or mathematics lessons that focused on students getting the right answer. Participants with expanded responses would vaguely talk about students involved in schemes of thinking but were not able to elaborate. Notions of students making connections, applications, and reasoning were categorized as progressive.

Themes for conceptions of pedagogical approaches were also categorized as traditional, expanded, or progressive. Traditional approaches were ones in which the lessons were teacher directed and instruction focused on fact learning. Expanded approaches represented approaches that were not completely teacher directed but did not focus on conceptual development. Progressive views were indicated by data that focused on inquiry-based approaches to develop understanding.

Knowledge and development of conceptions of common approaches in teaching mathematics and science varied. Responses were categorized based on recognition of similarities in approaches for teaching mathematics and science. Quotations were pulled from participants to reflect the big ideas for each category. Results are explained according to conceptions of tools, processes for learning, pedagogical approaches, and commonalities in science and mathematics teaching.

Data Analysis: Phase II

Data sources for Phase II included five mathematics teaching observations for Jane and four mathematics teaching observations of Kate, follow-up interviews after each observation, lesson plans, and an open-ended final reflection. The lesson plans served as a means of seeing at a glance if the observed lesson was what the preservice teacher had planned. The follow-up discussions were important to gain information on the student teacher's goals for the lesson and decisions that went into the structure and implementation of the lesson. The final reflection was similar to the final reflection from the methods course and provided another opportunity for the preservice teacher to reflect on their teaching experiences.

The constant comparative method (Glaser & Strauss, 1967) was used to find conceptions of mathematics teaching that emerged from the varying data sources. For each student teacher, each interview, observation, lesson plan, final reflection was coded based on the research questions (Merriam, 1998). Pieces of information that were striking to the researcher with regard to preservice teachers' thinking about how they linked ideas in practice across disciplines were noted for each piece of data (Merriam, 1998). Codes were determined based on words or phrases from the participants, conclusions from the researcher, or connections to existing research (Glaser & Strauss, 1967; Merriam, 1998). Data about tools, use of tools, plans involving tools and so forth were labeled with a T. Data about processes that took place during the lesson were labeled with a P. Information about pedagogical approaches was labeled with a PA. Data that referred to the learning cycle was coded as LC. Lesson plans were labeled as LP, observations as O, follow-up interviews as FI, and final reflection as FR. For example, Jane's lesson plan for the first observation stated "Review of measuring to the nearest inch" (J, LP, 4/14). In the observed lesson Jane did review how to measure to the nearest inch using items on the overhead projector. These statements were both coded as "tools for measurement". Since Jane led the students step by step through a series of measurements this was also coded as "teacher directed". During the follow-up discussion when asked "In what ways did you use tools for conceptual development" Jane said "Showing them the different items on the projector" (J, FI, 4/14). This was coded as "tools for measurement-teacher directed". Then the first teaching observation and follow-up discussion was read through again for the case to determine if commonalities existed that could group some of the items together or if other generalizations became apparent (Merriam, 1998). Comparing lesson plans to teaching observations to follow-up discussions provided verification of the data. For example, the researcher could see that in the lesson plan the students would be measuring, the students somewhat measured in the teaching episode, and in the follow-up discussion the student teacher confirmed that the lesson did not go as she had planned. This process of constant comparison continued for each set of data for each case (Charmaz, 2006; Glaser & Strauss, 1967; Merriam, 1998). Once all of the coding had been completed a table was constructed for each participant (See Appendix J for sample in overall appendix section). All of the codes for tools were placed in one section in chronological order. All of the codes for processes were placed in another section in chronological order. Codes for pedagogical approaches and the learning cycle were also placed in sections by chronological order. Codes were then regrouped to fit like items together (Saldana, 2009). For example, if the researcher noted that students made towers and then this came up during the follow-up discussion then those items were placed together. Examining the codes together allowed the researcher to then narrow the codes to succinctly represent the data. These narrower codes were placed in another column next to the lengthy code list (Saldana, 2009).

Once the data collected from the student teaching experience had been coded, the information was compared to the data from the methods course study. Data from the methods course had been examined in the same way as the student teaching. Therefore, the code list for the participants was pulled from the methods course data. The coding for the methods course was also in a similar table for tools, processes, pedagogical approaches, and the learning cycle. Codes for tools during methods class and tools for student teaching were read through to determine similarities, differences, or changes. This continued for processes, pedagogical approach, and learning cycle codes. The researcher tried to determine what changes, if any, occurred from mathematics-science methods class to student teaching in understanding and development of approaches in mathematics. The codes were examined in chronological order to determine shifts or changes in practice. Systematic searches were made to find corroborating or contradictory evidence. Generalizations then were made within each case across the different periods of data collection. Finally the two cases were compared.

In student teaching Jane and Kate had different conceptions of tools, processes, and approaches for teaching mathematics. Quotations were pulled from the data to reflect the big ideas for each category. Results are explained according to conceptions of tools, processes for learning, and pedagogical approaches.

Ethical Considerations

Following the guidelines of the Internal Review Board for the institution participants were informed of any risks or discomforts in the informed consent letter (American Educational Research Association (AERA), 2004). Participants were at risk for loss of confidentiality and coercion. To address the coercion factor at the end of Phase I a third neutral party distributed the consent forms. The consent forms were placed in a sealed envelope and delivered to the researcher at the beginning of the next semester. Coercion was not a risk for Phase II since the researcher was not an intern supervisor and presented the consent forms herself.

In order to ensure confidentiality a code list was developed. All documents for Phases I and II were given a code name to replace the name of the participant. The code name list was destroyed as well as all original hand written documents. All documents remaining were only designated by the code name. Furthermore, the names of schools systems, schools, cooperating teachers, or students were not recorded in any way as to maintain the confidentiality of the sites in which the research took place. In the narrative of the cases, pseudonyms were given for each of the participants.

Participants also were informed that the research may not have any direct benefit for individual but that the information may help others working with preservice teachers gain a better understanding of how preservice teachers think about common approaches to mathematics and science (AERA, 2004). Finally, the participants were able to withdraw from the study at any time (AERA, 2004). They were informed that if they decided to withdraw that it would not hurt any relations with the institution or the department.

Data Triangulation

Triangulation of information was used to ensure reliability of the study (Scott, 2007; Yin, 2009). This process of examining the converging information from the multiple resources is known as triangulation (Yin, 2009). Specifically this study used a multiple case design in which multiple cases were examined (Merriam, 1998; Yin, 2009). In data triangulation data sets were collected from the same participants at different points in the study: a pre-test was given on the first day of the semester, participants completed weekly blogs, a post-test was given on the last day of the semester, and notes and observations were made throughout the semester during Phase I (Denzin, 1970 in Scott, 2007). Multiple data sets mean that redundancy or repeatability of information may occur (Stake, 2005). Reoccurrences in the data help support the findings (Stake, 2005).

Triangulation of data meant comparing the different data sources, blogs, pre-tests, post-test, and field notes, to substantiate the findings (Oliver-Hoyo & Allen, 2006). Denzin and Lincoln (2003, 2005) proposed that triangulation was an "alternative to validation". Similarly, Adami and Kiger (2005) determined that triangulation should be for the purpose of completeness. Richardson (In Denzin & Lincoln, 2003) likened triangulation to seeing the different facets of a crystal. "Triangulation is the display of multiple, refracted realities simultaneously" (Denzin & Lincoln, 2003, p. 8). In examining the different facets, researchers look for convergence of information (Oliver-Hoyo & Allen, 2006). Sometimes near approximations are determined if complete convergence cannot be made (Oliver-Hoyo & Allen, 2006). "The higher the convergence, the greater the confidence that the measure was capturing the phenomenon being studied" (Adami & Kiger, 2005, p.20).

Data for each participant were compared to determine converging ideas (Adami & Kiger, 2005; Denzin & Lincoln, 2003; Oliver-Hoyo & Allen, 2006). Information from the pre-test and the post-test were compared to see a change in thinking from beginning to end. This information was compared in relation to blog entries. This analysis was conducted for each person in the study. Then the information was examined across participants to establish similarities and differences among the group. This same process occurred for participants in Phase II as well. After the data from participants for Phase II were coded their responses were compared to Phase I to determine any changes from methods course through student teaching. For participants in Phase II this meant a triangulation of information from both sets of data.

CHAPTER 4: ELEMENTARY PRESERVICE TEACHERS' CONCEPTIONS OF COMMON APPROACHES TO MATHEMATICS AND SCIENCE DURING METHODS COURSE

Abstract

This study investigated preservice teachers' thinking about common approaches to mathematics and science education for elementary children in grades K-6. Specifically, this study focused on preservice teachers' thinking on the use of tools for conceptual development, processes for meaningful learning, and common pedagogical approaches for mathematics and science. The study took place during jointly enrolled science and mathematics methods courses. The learning cycle was a common approach used in the methods courses and used by elementary preservice teachers in the field. The nature of the preservice teachers' understandings was examined through several data sources: open-ended pre and post-course tests, and weekly blogs. Results indicated varied conceptions of tools, processes, and approaches in science and mathematics teaching at the beginning of the methods courses. Many of the participants initially thought of science and mathematics as being approached in different ways, such as science involves experiments and mathematics focuses on solving problems. All of the participants expressed broadened ideas about teaching mathematics and science at the end of both methods courses. At the end of the semester 82 percent of preservice teachers recognized commonalities in teaching approaches for mathematics and science, including use of inquiry as well as the use of the learning cycle.

Introduction

In the United States, as well as other countries, concerns have been raised about the quality of science and mathematics teaching (National Commission on Excellence in Education, 1983; National Science Board (NSB), 2004). The National Council for Teachers of Mathematics (NCTM) (2000), the National Research Council (NRC) (1996), and the American Association for the Advancement of Science (AAAS) (1993) have constructed frameworks for reform to promote quality science and mathematics programs. Examining the mathematics and science standards documents reveals similarities in goals for science and mathematics, to move away from memorization and rote learning and instead to focus on conceptual understanding (Kind, 1999; NCTM, 2000; NRC, 1996; Steen, 1990). However despite reform efforts, the problem persists due to the fact that preservice teachers are often products of a traditional science and mathematics classroom that focused on repetition and memorization with little attention to understanding (Taylor, 2009). Since many of today's preservice teachers lack a model and understanding of standards-based reform teaching (Conference Board of the Mathematical Sciences (CBMS), 2001), approaching teacher development from a perspective of commonalties in mathematics and science teaching could help elementary preservice teachers better understand how to teach mathematics and science.

Since technology in the workplace has eliminated positions that require minimal skills, development of approaches in preservice teacher education programs that promote the preparation of elementary teachers with 21st century skills, creativity, critical thinking, communication, and collaboration, is important (Partnership for 21st Century Skills (P21), 2009). These same skills are foundational principles in the science and mathematics standards (NCTM, 2000; NRC, 1996). The standards documents promote active learning, learning for understanding of concepts, use of a variety of assessment techniques, and a move from lower order thinking skills to higher order thinking skills (NCTM, 2000; NRC, 1996; Tal, Dori, Keiny, & Zoller, 2001). Furthermore, standards in mathematics and science call for similar approaches in teaching including; use of tools for concept development; use of processes that include problem solving, reasoning and proof, communication, connections, and representations; and inquiry-based pedagogical approaches (Goodnough & Nolan, 2008; Justi & van Driel, 2005; NCTM, 2000).

In response to the standards documents efforts have been made in preservice teacher methods courses to prepare elementary teachers to appropriately teach science and mathematics in reform-minded ways (Kistler, 1997; McGinnis, Kramer, & Watanabe, 1998; Plonczak, 2010). Teacher development programs have designed mathematics classes for elementary preservice teachers that focus on problem solving and reasoning (Kistler, 1997), created courses that fostered connections between science and mathematics teaching (McGinnis et al., 1998), and developed courses focused on inquiry-based teaching in both mathematics and science (Plonczak, 2010). Teacher educators have also worked on the development of methods courses that integrated mathematics and science and used common instructional strategies (Beeth & McNeal, 1999; Lonning & DeFranco, 1994, 1997; Lonning, DeFranco, & Weinland, 1998; Stuessy, 1993; Steussy & Naizer, 1996). However, their concerns were in the development and integration, or combining, of mathematics and science. They recognized the common approaches within the methods classes but the conceptions of the commonalities of the preservice teachers were not the focus of their research.

This research attempted to address how preservice teachers think about the processes that occur similarly within science and mathematics teaching. This research focused on preservice teachers' conceptions of teaching science and mathematics, while in methods courses that utilized common approaches, and how their conceptions changed during the science and mathematics methods classes. In order to examine the response preservice teachers had to those similar processes, the participants' science and mathematics methods courses were approached from a similar pedagogical perspective utilizing learning cycle approach to teaching.

For this study the learning cycle offered a way of incorporating similar teaching methods of using tools for conceptual development (Chick, 2007; Fuller, 1996; Hill, 1997), discourse (Akerson, 2005; Heywood, 2007; Williams & Baxter, 1996), assessing student knowledge (Manouchehri, 1997; NCTM, 2000; NRC, 1996) inquiry-based teaching (Morrison, 2008; Manouchehri, 1997; NRC, 1996; Weld & Funk, 2005), and reflection (Bleicher, 2006; Hill, 1997; Manouchehri, 1997). Although the learning cycle has its roots in the science field (Bybee, 1997; Atkin & Karplus, 1962), the tenets align closely with the national mathematics standards. Preservice teachers were then expected to use the learning cycle approach in their courses and its laboratory teaching experiences.

The purpose of this study was to investigate how preservice elementary teachers relate, understand, and use the common or shared teaching practices for effective mathematics and science learning. The study examined preservice teachers' conceptual understanding of the learning cycle, an inquiry-embedded teaching approach for mathematics and science, while the preservice teachers were in their science and mathematics methods courses. Conceptions of pedagogy, tools for conceptual development, and processes for meaningful learning were examined for mathematics and science teaching from a qualitative perspective. The research questions of this study were: (1) What are preservice teachers' conceptions of tools for conceptual development, processes for meaningful learning, and pedagogical approaches prior to and after taking the mathematics-science methods courses? (2) What changes, if any, in development of knowledge and understanding of the common approaches between mathematics and science occurred while taking the mathematics-science methods course?

Background

Standards Documents

Like the launching of Sputnik, the release of *A Nation at Risk* by the National Commission on Excellence in Education (1983) sparked renewed concerns with the education system of the United States (Wong, Guthrie, & Harris, 2003). In particular, the resulting efforts focused on raising expectations with the development of standards throughout the educational system (Wong et al., 2003). Those standards came about from the efforts of the National Research Council (NRC) (1989, 1996), National Council of Teachers of Mathematics (NCTM) (1989, 1991, 1995, 2000, 2006, 2009), and the American Association for the Advancement of Science (AAAS) (1993). The National Research Council published *Adding it up* (2001): a report that described proficiency in mathematics as conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. Most recently the Common Core State Standards Initiative (2010), headed by the National Governors Association and Council for Chief State School Officers, developed standards for language arts and mathematics that focused on reasoning, critical thinking, and problem solving. The *National Science Education Standards* (NRC, 1996) focus on processes for students to develop an understanding and reasoning about science in an active learning process.

Standards have been developed for teachers and teacher preparation programs as well. Interstate New Teacher Assessment and Support Consortium (INTASC) developed general standards for new teacher candidates (n.d.). The Conference Board of the Mathematical Sciences (*2001),* in *The Mathematical Education of Teachers,* focused their standards and recommendations on what teachers and teacher preparation programs needed to have successful mathematics programs for educators. The National Science Teachers Association (NSTA) created a similar document, *Standards for Science Teacher Preparation* (NSTA, 2003). The resulting documents call for teacher candidates to be able to design, implement, and integrate teaching that makes content meaningful through inquiry and problem solving processes.

Commonalities in Standards Documents. When examining the elements of science and mathematics it is clear that similarities and differences exist between the two subjects. Mathematics is considered to be the language of science and science is dependent upon mathematics (Shapiro, 1983; Steen, 1990). Although there are differences in the elements that make up science and mathematics fields, there remain common ways of approaching the subjects (Steen, 1990). The standards documents promote mathematics and scientific literacy; being able to ask, find, and determine answers (Kind, 1999; NCTM, 2000; NRC, 1996; Steen, 1990). Science and mathematics standards call for students to develop deep conceptual understanding (NCTM, 2000; NRC, 1996; Steen, 1990). In order for students to become scientifically or mathematically literate and develop conceptual understanding, teachers have to create active learning environments (Kind, 1999, Steen, 1990). The active learning environment, recommended by the standards documents, is often likened to a constructivist philosophy of teaching in which students engage, explore, examine phenomena, and explain their understanding (Kind, 1999, Steen, 1990).

Just as mathematics and science content are intertwined so are the common approaches to teaching science and mathematics (NCTM, 2000; NRC, 1996). At the heart of the science and mathematics standards are common processes for meaningful learning, use of tools for conceptual development, and pedagogical approaches (NCTM, 2000; NRC, 1996). These processes include problem solving, reasoning and proof, communication, connections, and representations (Goodnough & Nolan, 2008; Justi & van Driel, 2005; NCTM, 2000). In mathematics, students are asked to solve problems, reason about their answers and demonstrate proof, represent their work, and communicate their findings (NCTM, 2000). Similarly in science, students are expected to be able to ask questions and then find the answers to those questions, validate findings, explain their findings, and be able to evaluate the conclusions of others (NRC, 1996). Furthermore, in mathematics and science students are expected to make connections or identify relationships between and among concepts and areas of study (NCTM, 2000; NRC, 1996).

Learning Theory and the Learning Cycle

A complex framework of generalizations, ideas, and relationships composes the nature of mathematics (Molina, Hull, Schielack, & Education, 1997) and the nature of science (NOS) (Akerson & Donnelly, 2008). In order to develop the skills to make generalizations, understand ideas, and examine relationships conceptual learning must be developed (Molina et al., 1997). Underlying assumptions about the nature of learning mathematics and science for conceptual understanding as articulated in the standards documents are founded on the idea that learning is an active process (Kind, 1999; NCTM, 2000; NRC, 2000; Tal et al., 2001). On a physiological level, Zull (2002) found that sensory experiences entered in the sensory cortex of the brain, were processed and actualized in the integrative cortex, and new ideas were tested in the motor cortex. From a sociological perspective, adults have observed children tasting, touching, smelling, and feeling the world around them, incorporating and reflecting on the new ideas, and actively testing the new ideas (Schmidt, 2008; Zambo & Zambo, 2007). Similarly adults undergo the same processes when learning new material: consciousness of a new idea, investigation of the new idea, and finally use of the new idea (Schmidt, 2008). This process of active learning has been called the learning cycle.

The learning cycle reflects a natural form of learning that has persisted with child and adult (Lawson, Abraham, & Renner, 1989; Schmidt, 2008). Schmidt (2008) described the natural learning in this cycle as consisting of “awareness, exploration, inquiry and action” (p.12). It was during the late 1950s and early 1960s, in which educational reforms were in demand, that Atkin and Karplus (1962) developed their model for teaching and learning science which focused on the natural active learning of children and later became known as the learning cycle. The Atkin/Karplus model consisted of three phases: exploration, invention, and discovery. Furthermore, the phases of the learning cycle in the Atkin/Karplus model align closely with Piaget’s theory of learning and in particular the processes of assimilation, accommodation, and organization (Abraham and Renner, 1983; Bybee, 1997; Kratochvil & Crawford, 1971; Renner & Lawson, 1973). The three phases of the Atkin/Karplus model, exploration, invention, and discovery, were expanded to five phases (Bybee, 1997). The five phase model still incorporated the initial phases of the Karplus/Atkin model (Bybee, 1997) and became known by Lawson and others on the Biological Sciences Curriculum Study (Withee & Lindell, 2006). The five phases included engagement, exploration, explanation, elaboration, and evaluation (Bybee, 1997).

Although the learning cycle has its roots in the science field (Bybee, 1997; Atkin & Karplus, 1962), the tenets align closely with national mathematics standards. Marek (2008), in his explanation of the learning cycle, also provided examples of the learning cycle for science and mathematics lessons. The mathematics standards promote students working together (NCTM, 2000), as recommended in the exploration and elaboration phases (Bybee, 1997). Using concrete tools and solving problems to develop a deep understanding of the concepts is core to the mathematics standards (NCTM, 2000) and aligns with the exploration, explanation, and elaboration phases of the learning cycle (Bybee, 1997). According to the mathematics standards students generate their own mathematical questions (NCTM, 2000), a part of the engagement phase (Bybee, 1997), and students generate conclusions (NCTM, 2000), a part of the explanation phase (Bybee, 1997). The exploration, explanation, and elaboration phase supports a focus on thinking and reasoning skills that lead to conjectures or arguments about the mathematics being examined (Bybee, 1997; NCTM, 2000).

In addition, components of inquiry-based teaching are evident in the learning cycle (Gee, Boberg, & Gabel, 1996; Tracy, 1999; Withee & Lindell, 2006). Inquiry-based teaching involves the exploration of students around a central idea, formulation of questions, investigations to answer the questions, and reflection of learned ideas (Morrison, 2008; Tracy, 1999). Furthermore, the learning cycle approach provides a method for structuring inquiry-based lessons, and is considered an inquiry embedded approach (Marek, Maier, & McCann, 2008; Marek & Cavallo, 1997).

Research on the Learning Cycle

Research has been conducted with the learning cycle in the K-12 setting (Boddy, Watson, & Aubusson, 2003; Cardak, Dikmenli, & Saritas, 2008; Liu, Peng, Wu, & Lin, 2009; Oren & Tezcan, 2009; Soomor, Qaisrani, Rawat & Mughal, 2010), in higher education (Illinois Central College, 1979; Walker, McGill, Buikema, & Stevens, 2008), with preservice teachers (Haefner & Zembal-Saul, 2004; Hampton, Odom, & Settlage, 1995; Hanuscin & Lee, 2008; Morrison, 2008; Park Rogers & Abel, 2008; Settlage, 2000), and with in-service teachers (Gee et al., 1996). Researchers have concluded that K-12 students using the learning cycle perform better on content questions than students in a traditional science classroom (Cardak, Dikmenli, & Saritas, 2008; Ergin, Kanli, & Unsal, 2008; Ören & Tezcan, 2009; Soomer et al., 2010). Furthermore, Boddy et al. (2003) found that the use of the 5E learning cycle promoted higher order thinking skills in primary age students. When working with a primary teacher to help the teacher develop skills in using inquiry with the 5E model, the researcher found the students were more involved and more on task than they would have been in a traditional science lesson (Clark, 2003).

Research with elementary pre-service teachers and the learning cycle have indicated similar results. Hanuscin and Lee (2008) used the learning cycle with their elementary preservice teachers during the science methods course. They found the learning cycle was an effective approach with elementary preservice teachers. After using the learning cycle as a model for teaching science their preservice teachers were able to apply that knowledge to deign tiered lessons with the learning cycle. Also, direct teaching of the learning cycle approach positively influenced elementary preservice teacher's efficacy of teaching science with the learning cycle during a science methods course (Settlage, 2000). Results from studies in science methods classes also indicated that elementary preservice teachers embraced the learning cycle due to dissatisfaction in the way they experienced science in school (Lindgren & Bleicher, 2005). Their understanding of the learning cycle improved with the continued exposure of the learning cycle in methods class, but some had a difficult time conceptually changing their ideas about teaching science (Gee et al., 1996; Lindgren & Bleicher, 2008). Elementary preservice teachers had greater understanding of some aspects of the learning cycle, but their conceptions of implementation of the learning cycle did not always follow the way the intended learning cycle (Hampton et al., 1995; Marek, Laubach, & Pedersen, 2003).

There is a scarcity of research on the learning cycle and mathematics education. The research that exists on preservice teachers and the learning cycle focuses primarily on science

(Lindgren & Bleicher, 2005; Marek et al, 2008; Urey & Calik, 2008). However, researchers teaching preservice teachers have provided examples of the learning cycle and mathematics (Marek & Cavallo, 1997; Marek et al., 2008; Simon, 1992). Marek (2008) described a science lesson in which students measured the circumference of objects to make a conclusion about the relationship of the circumference and diameter of circles. His description illustrates how the learning cycle could be used in mathematics teaching. Although his example was for a science lesson, it very easily could have been for a mathematics lesson on understanding area of circles. Similarly, Marek and Cavallo (1997) described the use of the learning cycle for students to understand measurement and geometry concepts. Simon (1992) recognized the use of the learning cycle in mathematics methods courses. He described a mathematics methods class in which teacher candidates solved a problem situation, discussed solutions, and extended new ideas into other problem situations.

Methods

Research Design

Twenty-two elementary preservice teachers were invited to share their understandings of common approaches in science and mathematics teaching while in their methods classes. Multiple sources of data were collected to provide triangulation of data (Yin, 2009). Furthermore, evidence in the study took the form of an open-ended pre-test, open-ended post-test, and weekly weblogs, or blogs (Merriam, 1998; Yin, 2009). This study used a multiple case design in which multiple cases were examined (Merriam, 1998; Yin, 2009).

Context of the Study

Elementary preservice teachers jointly enrolled in science and mathematics methods classes were the focus of this study. The principal researcher was the mathematics methods instructor who planned and worked with the science methods class professor. As the mathematics methods instructor, the researcher focused on the development of the preservice teachers in the mathematics methods course and in the mathematics field placements. The sample included 22 of the 25 students enrolled in the undergraduate courses.

Participants completed the science portion the first five weeks of the semester and the mathematics portion the second five weeks of the semester. Since the study took place during the summer semester, participants attended class or a field experience every day of the week. Science lessons in the on-campus portion of the science class included lessons from *Full Option Science System* (Foss) (Lawrence Hall of Science, 2003), *Science Technology for Children* (STC) (National Science Resources Center, 2003), and *Insights* (EDC Science Education, 2003). Example activities in the science methods class included a series of inquiries on earth science concepts in which rocks were explored. For the mathematics portion of class, materials consisted of materials from NCTM and the *Investigations* curriculum (Pearson Education, 2007). Example activities in the mathematics methods class included a series of activities in which three-dimensional figures were used for a volume unit. In both classes preservice teachers participated in investigations and experiments, discussions, and readings (Chick, 2007; Heywood, 2007; Hill, 1997). The learning cycle was used as the common pedagogical approach.

Participants who completed elementary science and mathematics activities taught with the learning cycle approach in the role of a student. After these teaching episodes, students then took on the role of a teacher in peer teaching and examining the pedagogy of the teaching episode. Participants completed weekly blogs, as a course requirement, pertaining to their teaching practice and aspects of the learning cycle each week of the science portion of the semester. The themes of those blogs were repeated during the mathematics portion of the semester (see Appendix C). Preservice teachers also participated in field experiences to give them an opportunity to practice teach mathematics and science. Although participants were in differing field placements for the science and mathematics portions of the methods classes, they were expected to design and teach lessons using the learning cycle. Field placements for science were at summer academic camps including an outdoor ecology preserve and a local school. Field placements for mathematics were at two summer programs held by the local Boy's and Girl's Clubs of America.

Data Collection

Multiple methods of data collection took the form of an open-ended pre-test, open-ended post-test, and weekly weblogs, or blogs (Merriam, 1998; Yin, 2009). The open-ended pre-test was administered on the first day of class at the beginning of the semester (see Appendix A). A similar open-ended post-test (see Appendix B) was administered on the last day of the semester. Questions on the pre-test and post-test were designed to elicit information about participants' conceptions of tools and processes for learning, pedagogical approaches, and commonalties in approaches to mathematics and science. Participants completed weekly blogs (see Appendix C) concerning science and mathematics teaching. Blogs for the first five weeks focused on tools, processes, and approaches to science teaching. Similar blogs were used the second five weeks that focused on tools, process, and approaches to mathematics teaching. In addition, the researcher recorded notes on the actual teaching practices of the participants while in the field.

Data Analysis

The constant comparative method (Glaser & Strauss, 1967) was used to find conceptions of mathematics and science teaching that emerged from the varying data sources. First level coding for category construction occurred with each blog, pre-test, and post-test (Merriam, 1998). Keeping in mind the research questions, the researcher attempted to create categories that would “reflect the purpose of the research” (Merriam, 1998, p. 183). Pieces of information that were striking to the researcher in regard to conceptions of tools, processes, pedagogical approaches, and similarities in teaching science and mathematics were noted for each piece of data (Merriam, 1998). Categories were determined based on words or phrases from the participants, conclusions from the researcher, or connections to existing research (Glaser & Strauss, 1967; Merriam, 1998). For example, when Person 1 on the pre-test described children in the field placement taking apart machines to understand how the machines were designed, the researcher coded based on the phrasing of the respondent as “took apart machines for understanding”. Then the first blog for Case 1 was read through for category construction. New categories were designated based on new information: “need for fun”, “benefits”, and “traditional approach criticism” (Phase I, Person 1-Blog 1, 2008). The researcher made a list of the codes from the first three data sets (Merriam, 1998).

From the list of initial codes the researcher referred to the research questions and added prefixes to the codes (Merriam, 1998). For example, on Person 1-pretest, the researcher noted that the respondent indicated group activities and hands-on activities as being a common to teaching mathematics and science. The researcher coded as “CA-group activities”. The research questions dealt with five main areas: tools for conceptual development, designated with a T in the coding process; processes for learning, designated with P; pedagogical approaches, designated with PA; and more specifically common approaches between mathematics and science, designated with CA; and change in thinking, designated as CIT. Since the learning cycle was used as a common approach in the science and mathematics methods course then aspects of the learning cycle were designated with an LC. Preservice teachers also added many personal experiences about learning mathematics and science. A category was designated for personal experience (PE) in order to differentiate it from their current practice.

A chart was made for each participant that included the T, P, PA, CA, CIT, LC, and PE. Codes were placed in the chart for each person in chronological order with a source code at the end. “Pre” and “Post” were source codes for the pre-test and post-test. The letter B and a number were used for blog source codes. For example on Person 1 under T, “Took apart machine in FEP b3, Promoted fun b3”. Based on the codes for each area the researcher refined the code list.

After all of the level two coding was completed the researcher examined data across the cases to make further generalizations. These generalizations were organized into the themes for each category. Three themes emerged for tools and processes: traditional, expanded, and progressive. Themes for approaches were categorized as traditional, mixed, or hands-on.

Categorical Themes. Based on their responses, participants’ conceptions of tools for math and science were categorized into three categories: traditional view of tools, expanded view of tools, or progressive view of tools. Traditional views of tools represented following a traditional textbook or only focused on computation. Responses that had a mixture of students conducting experiments, worksheets, textbook learning, and students looking at pictures were classified as expanded view of tools for science. Responses in which tools were used for primary concepts such as shapes, money, or counting were included in the expanded view. The progressive category for science and mathematics included comments about students exploring in nature, physical knowledge activities, or students completing hands-on tasks.

In examining how preservice teachers conceived of processes for learning their responses fell into three distinct categories. Processes for learning were categorized as traditional, expanded, or progressive. Processes in which students focused on students finding answers were categorized as traditional. Preservice teachers in this category saw experiments as a means for students to find predetermined outcomes or mathematics lessons that focused on students getting the right answer. Expanded processes were process indicated beyond just the right answer, but still limited in scope. Examples of expanded processes indicated responses that indicated students should see or observe. However, notions of students making connections, applications, and reasoning were classified as progressive.

There were varying thoughts on pedagogical approaches for science and mathematics. Pedagogical approaches were categorized as traditional, expanded, or progressive. Traditional approaches were ones in which the lessons were teacher directed and instruction focused on fact learning. Expanded approaches in science represented ideas that science should include experiments, observation, or research. Expanded approaches in mathematics focused on approaching math with real-world mathematics Progressive views were indicated by data that focused on inquiry-based approaches to develop understanding.

Quotations were pulled from participants to reflect the big ideas for each theme. Results are explained according to conceptions of tools, processes for learning, pedagogical approaches, and commonalities in science and mathematics teaching.

Results

Conceptions of Tools

Science. Participants more readily accepted the use of concrete tools for concept building in science than for math, as indicated in Table 1. Hands-on learning was a common idea of tools in science at the beginning of methods class. By the end of methods class seventeen preservice teachers thought tools in science should be for hands-on learning. A few maintained a limited view of tools in science for measurement or for right answers.

Table 1

Thematic Categories Conceptions of Tools

Tools	Traditional	Expanded	Progressive
Science	Teacher controlled experiments; Science projects; understand the science book; Stories to tell; use tools for measurement	Experiences, worksheets, activities, and experiments; observe nature	Hands-on learning; Physical knowledge activities; Memorable concrete experiences
Pre (n)	6	3	13
Post (n)	3	2	17
Mathematics	To do a problem or get a right answer, computation, for skills practice, facts, and review games Tools as a question	money, tools for counting, time or shapes	Games and activities, to teach the concept, creative way for students to understand; To see relationships or understand the lesson better
Pre (n)	8	8	6
Post (n)	8	5	9

Six participants initially held a traditional view of tools in science. They considered tools to include teacher-controlled experiments, science projects, the science book, or stories. These tools were used in a teacher led manner. In such a context, students were being informed of the science concept rather than learning about it for themselves. By the end of the semester three participants held a traditional view of tools in science. The preservice teachers continued to see tools as a means of performing calculations. They did not see tools in a larger context as a means to foster conceptual understanding:

> A concrete tool that would be used in a science lesson would be a thermometer. Children can be given a problem such as: find the average body temperature or measure this glass of water to see how hot/cold it is. (Person 16, Post-test)

Three preservice teachers had an expanded view of tools in science at the beginning of the methods courses. They recognized tools in science for more than measurement tasks, but they did not see the full potential of tools. They also were vague in their articulation of the role of tools. They would say tools were for students to act like a scientist, but they did not provide further explanation of what was meant by the statement: “By having students use hands-on tools in experiments themselves, they are acting like scientists” (Person 9, Post-test). By the end of the semester only two students held an expanded view because one of them now held a more progressive view.

Thirteen participants expressed the use of tools for hands-on learning in science. Respondents with this view believed that, “When students have a hands-on experience with the lesson they are able to learn more from the lesson” (Person 2, Pre-test). By the end of the semester 17 out of the 22 participants believed tools in science were to develop concepts. The field experiences provided preservice teachers with opportunities to use tools to teach science:

> I taught a lesson on how much water is on Earth. They were able to use concrete materials to pour beans into a gallon container to see how many pints are in a gallon and so on. They made a measurement book to see it for themselves. (Person 5, Post-test)

Mathematics. Participants more readily accepted tools in science than in math initially. Traditional notions of tools in mathematics remained an underlying theme for eight of the participants, as indicated in Table 1. Although preservice teachers talked about using tools for hands-on or inquiry-based learning in mathematics, eight participants were merely using tools to reinforce procedures. Their conceptions of tools were limited to computation tasks. Furthermore, those tasks were often for primary grades for such concepts as addition, subtraction, and counting money. Using tools to solve rote computation problems focuses the mathematics on getting a right answer rather than using tools for conceptual knowledge building. A typical response was: “Students understand the material being covered when they can use manipulatives; using cubes is great when teaching adding, subtracting, and even dividing” (Person 12, Pre-test). Those with a traditional view of tools in mathematics were focused on students using tools to determine the right answer. Five of the participants maintained a traditional view of tools at the end of methods classes. They continued to view tools for teaching primary concepts:

> Using play money because it makes counting money a lot easier when they can actually see it. Children are going to need to count money in real life situations so it is important that they know what it looks like. (Person 17, Blog 8).

Participants with an expanded view of tools in math saw tools for more than just computation but in limited ways. They relegated tools in math to visual representations of primary concepts, such as time and money. They did not consider that tools could be used to develop conceptual understanding of concepts. Often their school experiences provided the framework for tools in mathematics:

> One specific memory I have of using concrete tools in math was in my first grade class. Every week, we would be rewarded with pretend money for good behavior completed assignments, etc. Each Friday, we were allowed to use our “money” we accumulated throughout the week to buy something from the pretend store in the classroom. (Person 18, Blog 9)

Six preservice teachers held a progressive view of tools at the beginning of the methods classes. They believed that tools could help students understand concepts. These participants were asked to use tools to teach mathematics in a manner in which most of them did not experience as children. Their blogs often referred to memorization along with skill and drill experiences in school. However, they expressed dissatisfaction in the way they experienced mathematics in school:

> I like the fact that students can be life-long learners when using the learning cycle. If the learning cycle is applied in math it makes for better instruction and learning. If I would have had more hands-on activities when I was in school, then math would not have been so bad. I find the students do learn better with hands-on experiences and learning is fun and engaging." (Person 2, Week 6)

When they followed the standards based lesson, they saw the success in learning that could happen with the use of tools. The following is an example of a successful lesson in which the preservice teacher was uncomfortable at first using tools to teach a fraction lesson:

> I did the lesson with the equivalent fraction strips. They were a little confused at first but as we continued and played the game, they began to understand. When they placed their fraction, I had them place it where they thought it would go and tell me what percent it was. Rather than just having a sheet with equivalent fractions and percents for them to look at and learn, they actually had a chance to place actual cards in a place where it should go and strategize with their fractions of how to block others and what fractions they might have. (Person 4, Blog 10)

The field experiences verified their conceptions that tools in mathematics helped students understand and deepened their understanding of tools in mathematics. Nine of the 22 participants at the end of the semester recognized that tools in mathematics could be used to understand a concept and develop relationships between concepts. They described tools in terms of student using the tools to help build their knowledge: "Students can use geoboards to help their understanding of polygons. These experiences are very important for students to create their own knowledge" (Person 7, Post-test).

Conceptions of Processes

Traditional View. At the beginning of the semester a majority of the students had limited conceptions of processes for learning science and mathematics, as indicated in Table 2.

Table 2

Thematic Categories for Conceptions of Processes

Processes	Traditional	Expanded	Progressive
Science	Teacher led lessons in which students are passive learners	Articulates processes in a limited way Ex: Students observe experiments.	Views processes in a larger context to develop schemes of learning. Ex: Students conduct experiments to solve their own questions
Pre (n)	3	14	5
Post (n)	3	6	13
Mathematics	Processes for answers/ facts	Articulates processes in a limited way Ex: Students make observations	Views processes in a larger context to develop schemes of learning. Ex: Students figuring out and reasoning about mathematics
Pre (n)	7	11	4
Post (n)	6	4	12

Three preservice teachers thought of science processes in traditional ways and seven preservice teachers thought of processes in mathematics in traditional ways at the beginning of methods class. Traditional conceptions placed the students in passive roles with the teachers giving all of the information. Those with a traditional view of process articulated processes in teacher-directed and controlled lessons. The teacher's role is not one of a guide but rather the authority in the classroom. A typical statement for traditional processes in science was, "Teach a lesson, do the activity, let students explain how it worked and how they go together" (Person 4, Pre-test). A typical statement for traditional processes in mathematics was, “Teach the lesson, work together as a class and have students work independently” (Person 4, Pre-Test). In these scenarios the students are following the examples provided by the teacher and are not involved in problem solving. In both scenarios, students are completing a science or mathematics lesson in which the method has been given by the teacher. Since the method is known, they are, therefore, not reasoning, communicating, or making connections about the mathematics or science either. By the end of the semester those with traditional views had very little change in thinking.

By the end of the semester, three of the participants believed students should be making connections and seeing real-life applications in science. They expressed in some manner that students should be “doing” in science. However, six participants believed procedures and problems should be the focus for mathematics. They conceived of mathematics as ‘an exact answer’ and science as ‘changing’. They believed that students finding answers for themselves indicated good mathematics teaching. Participants with these views often interpreted not giving the students answers to rote problems as the focus of teaching. They would describe using aspects of the learning cycle to foster processes in mathematics but then describe a teaching episode in more traditional ways. Answers or facts were the goals of processes:

> Students worked to determine how many steps they would take in one mile and then one hundred miles. I observed the students as they worked in pairs. I listened carefully to their conversation to hear student thinking and to determine whether or not their thinking would lead them to the correct answer. (Person 3, Week 9)

They also considered students solving practice problems to be problem solving. On a lesson in which students were completing practice problems on making money change, a preservice teacher reflected, “I promoted inquiry by making it real life applicable and showing students how they could use what they are learning" (Person 3, Week 10). Thirdly, they interpreted participation in an activity as an example of inquiry-based teaching. A preservice teacher commented:

> In my lesson, the students were actually the concrete materials. I would use them to say 3 out of 6 are wearing jeans so what is the fraction and percent. They enjoyed this, and I could tell they were learning. We played Guess My Rule, and the children were very good at this activity. My lesson promoted inquiry because they were able to participate in the activity and think about what fraction and percent of things the students have in common. (Person 5, Week 10)

It is clear from these examples that what preservice teachers labeled as inquiry was a very naive view of inquiry.

Expanded View. Fourteen of the twenty-two participants initially held an expanded view of processes in science. They considered processes for science were more than understanding a science textbook. They recognized the importance of students experiencing science for themselves, but did not articulate processes beyond the level of observation. In a lesson on the Laws of Motion a preservice teacher responded, "These children were able to see what the laws were by creating things that dealt with it and learning first hand" (Person 5, Week 5). Eleven of the preservice teachers initially held expanded views of processes in mathematics in which processes were for more than answers, but still very limited in nature. By the end of the semester six participants had expanded views of processes in science and four participants held expanded view of processes in mathematics. Eight of the participants with an expanded view of science and seven of the participants with an expanded view in mathematics shifted to a progressive view by the end of the semester. The field experiences provided a framework for them to help students develop problems solving, reasoning, and communication in science and mathematics.

Progressive View. Initially five preservice teachers for science and four preservice teachers for mathematics held progressive views of processes. Preservice teachers who started out with expanded views in math developed more cohesive understanding of processes in science and mathematics teaching. They believed that students should reason for themselves about concepts and relate that knowledge to other areas. The field experiences provided a means for the preservice teachers to put the learning cycle into practice. By the end of the semester 13 of the 22 participants for science and 12 of the participants for math held progressive views of processes. Data sources indicated they were able to articulate processes in relation to lessons they had taught:

> So, I had the students go around and tell me why they thought there might be more or less raisins in each box and the students suggested that because the raisins were different sizes there might be more big ones that took up more space and made less as many raisins in the box or there might have been more smaller raisins making there more raisins in the box because of the room. I was really proud of the students' observations and predictions. I provided the students with an opportunity to build knowledge through real-life and hands-on activity. (Person 19, Week 10)

They conceived of processes as students reasoning, making connections, finding relationships, and justifying conclusions. They often articulated this in terms of students reasoning, students discussing their observations or findings with each other, or experiencing the concept: "I thought it was so interesting to see what these kids could design and everything they used to create their designs, and the reasoning they had behind their creations" (Person 6, Week 5).

Conceptions of Pedagogical Approaches

As with tools and process, participants held varying views about approaches to teaching science and mathematics, as indicated in Table 3.

Table 3

Thematic Categories for Conceptions of Pedagogical Approaches

Approaches	Traditional	Expanded	Progressive
Science	Teacher the lesson, do the activity, let students explain, teacher-led demonstrations in which students are passive learners, teacher shows models	Experiments, centers, nature walks	Hands-on Activities to construct knowledge, experience science for themselves
Pre (n)	7	6	9
Post (n)	4	7	11
Mathematics	Teach the lesson, work together, then students work individually, work by skill level	Math games, centers, real-life (i.e. play store)	Hands-on to build understanding, to see the math unfolding
Pre (n)	8	9	5
Post (n)	6	5	11

Traditional View. Initially, seven participants held traditional views about approaches for teaching science and eight participants held traditional views about approaches for teaching mathematics. Preservice teachers with this view believed that science and mathematics should be approached with the teacher demonstrating and the students completing a verification activity. With this approach the students are being told the information rather than experiencing it for themselves. Four of the seven for science and six of the eight for mathematics maintained their view of traditional approaches by the end of the semester. They tried to justify traditional approaches in science and mathematics with the learning cycle and hands-on approaches:

> I also believe that more traditional approaches can still be combined with the learning cycle. Reading in the textbook, completing worksheets and defining terms can be helpful for students as long as they are exposed to other approaches as well. (Person 7, Week1)

They liked the idea of a learning cycle and hands-on but still tried to negotiate how to incorporate hands-on into more traditional science and mathematics instruction. Some participants believed in a hands-on approach to teaching science and mathematics but under certain conditions. One participant believed in teaching with hands-on but only when the students had earned it through good behavior:

> I understand these kinds of activities must be implemented with a certain structure, perhaps spread out occasionally over a period of time. Kids view these types of activities as a treat, so promising them to get to participate in them would be something they could work towards. (Person 18, Week 5)

Similarly, a participant believed that the teacher must establish her authority and be in control of the classroom in order to use hands-on teaching: "The kids have a lot of fun and don't see the lessons as lessons but as fun activities. This laid back time is great, but when there is a lack of discipline and consequences, it can become an issue" (Person 3, Week 5). Her need for control over the classroom and students influenced her approach to teaching mathematics and science. Three of the participants indicated that hands-on approaches in science were for special occasions or when it was convenient for the teacher to implement:

> I do think there is usually some way to incorporate hands-on activities with each scientific concept you teach. The students will enjoy it more, and will be more likely to retain the information they learn. That said, I know that there are other times that call for more traditional instruction, but as long as the teacher keeps it interesting and

incorporates hands-on activities where it is possible, the students will have an enjoyable, meaningful experience. (Person 18, Week 4)

For three of the participants with traditional views in science and two with traditional views in math, the field experience and methods class impacted their conceptions of how to approach science and mathematics. They moved to progressive or expanded views by the end of the semester.

Expanded View. Six participants held expanded views for teaching science and nine participants held an expanded view for teaching mathematics. They believed in science that students should be involved in a combination of experiments, centers, observation, and research: "Having learning centers for children to learn or review different science centers" (Person 10, Pre-Test). In mathematics, they believed that the approach should focus on real-life mathematics and centers: "Real-life projects have value in everyday life like counting money. Role play like grocery store" (Person 14, Pre-test). Their description included more than the teacher delivering the knowledge, but not on the level of approaching science and mathematics for conceptual understanding. By the end of the semester there were seven participants who held expanded views in science, one more than the beginning of the semester. This can be explained in three preservice teachers with traditional views moving into the expanded view and three preservice teachers in the expanded view moving into the progressive view. Some preservice teachers with an expanded view also shifted into the progressive view by the end of the semester. For mathematics, four of the preservice teachers moved into the progressive view by the end of the semester, which left five in the expanded category.

Progressive View. Nine participants in science and five in mathematics believed science and mathematics should be taught with a hands-on approach. At the beginning of the semester they talked in general terms about hands-on or constructivist learning. They talked about students completing physical knowledge activities. They described students working in nature to learn about plants and insects. They described mathematics using learning centers and hands-on activities to develop understanding. Their teaching experiences in the field reinforced their conceptions and expanded their notions of teaching science and mathematics:

> At the Forest Ecology Preserve I taught a lesson about the basic needs for survival including food, water, shelter, and space. During the lesson I elaborated on shelter as the basic need and had the students build their own shelter. I followed the 5E's teaching model. I also provided the students with a very hands-on approach to learning by having them create their own shelter. By having them create their own shelter, they were able to make personal connections to what they were learning. (Person 19, Post-test)

Eleven participants believed that science and mathematics should be taught with a hands-on approach by the end of the semester. They felt they benefited from the learning cycle approach to hands-on lessons as well as the students:

> The lesson I did converting the gallon of beans into cups, pints, and quarts helped me learn so much better. I was able to actually see a gallon be converted into cups first hands. I hate to admit it, but before I only remembered the formulas used and did not exactly remember how many cups were in a quart and so on. This played a role in my learning and helped me remember why it works out as it foes. Using this concrete experience not only added to my learning, but it did to the children I taught. (Person 5, Week 9)

Common Approaches between Mathematics and Science

Initially most of the preservice teachers thought of mathematics and science as being approached in different ways, as indicated in Table 4.

Table 4

Thematic Categories for Approaches Between Mathematics and Science

	No similarities in approaches	Partial connections	Recognizes similar approaches for both mathematics and science
n	13	2	7
Pre	Sees as two different subjects with two different ways of teaching For example: science uses experiments and solve problems in mathematics	Sees connection of mathematics and science, but sees teaching them differently.	Science strategies can be used in mathematics. Both require critical thinking, physical knowledge activities Both hands-on activities and games to make interesting and fun.
n	2	2	18
Post	Sees as two different subjects with two different ways of teaching	Commented that hands-on could be used for both but described mathematics for finding the right answers.	Learning cycle for both; both involve inquiry, learning experiences, using lab activities, let students figure things out.

None of the students mentioned the learning cycle on their pre-test. Thirteen preservice teachers initially indicated that there were no commonalties between teaching science and mathematics. They indicated that science was for teaching plants and animals and mathematics was for teaching numbers. “Math deals with numbers, geometry, fractions, etc. Science deals with animals, plants, biology, etc” (Person 22, Pre-test). Only two preservice teachers saw mathematics and science as being approached differently at the end of the semester.

Two participants indicated partial connections initially between teaching science and mathematics. They saw that they had connections but should be approached differently. “Math and science both use critical thinking. Math and science are different in that science has more experimentation and math has more number problem solving” (Person 11, Pre-test). Two preservice teachers commented at the end of the semester that both science and mathematics is hands-on, but they described mathematics as finding the right answer.

Seven participants indicated that there were commonalties between science and mathematics teaching at the beginning of the semester. They indicated that science and mathematics both used hands-on learning: “Math is like teaching science because there are different types of math and science. Math and science also provide hands-on activities for learning. Science and math are similar in that we use each subject everyday” (Person 8, Pre-test). Eighteen participants indicated at the end of methods class that the learning cycle approach should be used for both science and mathematics teaching.

Students developed understanding of the learning cycle through methods classes and field placement teaching. Concepts of the learning cycle varied from seeing the learning cycle as steps to recognizing the learning cycle as a means for fostering developmental understanding. Some grappled with the learning cycle approach in comparison to the manner in which they were taught mathematics and science. With the learning cycle approach students are engaged and participate in an exploratory activity to bridge prior knowledge with new knowledge. Explanations often follow this exploratory stage. However, exploration followed by discussion is at odds with cookbook science lessons of traditional classrooms. Due to prior science teaching experiences, a preservice teacher believed that explanations were important before a hands-on activity:

> When they see things happen they tend to learn more. I think that hands-on is always a good way to go, but I also think there’s a time for explaining most likely before the

> hands-on activity. Students need instruction and explaining or they will just look at hands-on activities as play time. (Person 17, Week 4)

The learning cycle lessons in methods class provided an example for them to reflect on in their blog posts. Preservice teachers discussed the idea of explanation and hands-on and when explanation should occur in the lesson. Preservice teachers had to rethink the learning cycle approach in relation to their experiences. Preservice teachers thought:

> The important characteristic of the learning cycle is that it involves concept introduction following exploration. This surprised me when I first discovered this, because I originally assumed teachers explained the concepts to students, and then allowed the students to see examples of the concepts through activities. (Person 18, Week 1)

Preservice teachers also described advantages to the learning cycle in their blogs. They liked the idea of students being actively engaged in exploration. They felt that this active engagement helped to build students' background knowledge. They also felt that exploration set the stage for learning.

> The learning cycle, I feel, is a method of teaching that needs to be incorporated into mathematics. This is true because math, much like science, is easier to retain knowledge when there are activities that allow students to create his or her own knowledge." (Person 6, Week 6)

Eighteen out of 22 participants at the end of the methods classes did recognize the learning cycle could be used for both science and mathematics. They recognized the important role of concrete experiences in science and mathematics lessons. A typical statement was, "I now see how closely teaching mathematics and science can be related. I noticed that they both have an importance of using hands-on or concrete experiences to help the understanding of the lesson"

(Person 7, Post-test). They recognized the importance for students to figure concepts out. Furthermore, they recognized the learning cycle approach as a common approach to teaching science and mathematics. Some of them referred to their blogs as the source that helped them realize the learning cycle could be used for both subjects: “I was able to see similarities in math and science because some of the posts were the same such as dealing with the 5Es, concrete materials, hands-on activities and assessment in both math and science” (Person 16 Post-test).

Discussion

There were several positive outcomes from this study. First of all, preservice teacher seemed to benefit from the design of the science and mathematics classes. In their blogs they mentioned new ideas about tools, processes, and approaches in science and mathematics that they learned from the class investigations. Once they began working with children in the field, they recognized how well students responded to use of tools, hands-on processes, and the learning cycle format of lessons. They would comment that teaching the lesson with the hands-on on approach helped them personally have a better understanding of the concept. Secondly, they felt the learning cycle was appropriate for science and mathematics. Using the learning cycle in both methods classes provided a consistent approach for the preservice teachers. Bt the end of the semester 18 out of 22 preservice teachers recognized the learning cycle as a common approach to teaching science and mathematics. Teaching preservice teachers a common approach enabled them to focus on tools, processes, and implementation of the approach. Finally, many of the preservice teachers deepened their ideas about the use of tools, processes, and approaches in teaching science and mathematics. Eight preservice teachers shifted towards expanded or progressive views with the use of tools and processes in science. Only three participants shifted in their conceptions of tools in mathematics, but eight participants shifted in their views of processes for mathematics teaching. Five participants shifted in their views of how to approach science. Six preservice teachers shifted in their conceptions of how to approach mathematics. The class investigations, peer-teaching, and field experiences opened them the idea of teaching for conceptual understanding. Moreover, Hill (1997) found that when preservice teachers used concrete experiences in courses and with students in field placements, it set the stage for preservice teachers to achieve conceptual change due to bolstering self-confidence in teaching, gaining a sense of accomplishment, and deepening of mathematical understanding.

This research attempted to find out if elementary preservice teachers in a dually combined methods course using the same approach would recognize commonalities of those approaches. Preservice teachers consider science a subject in which students are supposed to be "doing" something (Gee et al., 1996). Research tells us that students should be "doing" in mathematics as well (NCTM, 2000). The "doing" of mathematics is not computation problems to solve or solving word problems that follow a pattern to practice a problem solving strategy (NCTM, 2000). In the case of the preservice teachers in this study they recognized science was for "doing". They wrote about science in terms on hands-on or experiments. We do not know what they mean by experiments, but their intent is clear that students are involved with concrete materials. For mathematics, it was different. Even though methods class focused on using tools and developing processes within the learning cycle approach, a few of the preservice teachers continued to try to conform to their primarily traditional experiences. Furthermore, those with traditional views of tools rigidly held onto those views. Their view of tools for answers is similar to an instrumental view. An instrumental view is a view of mathematics as a set of memorized formulas and rules (Skemp, 1976). Preservice teachers' instrumental view of mathematics perhaps creates interference in the way they understand the learning cycle, and commitment they have for it as a teaching method. Gee et al. (1996) were also disappointed to find that preservice teachers were not fully committed to the learning cycle as an approach for science. They believed that is was difficult for the preservice teachers to accept a different way to approach teaching science. Lindgren and Bleicher (2008) drew similar conclusions when some of the strongest science students were reluctant about the learning cycle as an approach for teaching science. However, students, who had negative science experiences or were dissatisfied with the way they were taught, embraced the learning cycle approach. For those in this study, with a traditional view of tools in science, it seemed they could shift to an expanded or progressive view because it still fit with the "doing" notion of science.

Processes similarly mirrored the use of tools. For those with traditional views of tools, they also commonly held traditional views of processes. They wanted students finding the right answer. Designing lessons requires teachers to understand the ideas and related concepts (Hill et al., 2008). The challenge lies in implementing lessons for students to use processes to see those ideas and relationships for themselves (Hill et al., 2008). For new teachers who are learning to teach, this is a challenging prospect. Many of the preservice teachers were able to articulate teaching in terms of processes for understanding by the end of the semester. Processes for reasoning and justification developed as preservice teachers worked with children in the field.

The learning cycle approach requires teachers to have strong pedagogy in science and mathematics teaching. This approach is different from what preservice teachers experienced in school. Therefore, they have to be willing to accept the approach used in methods class. The process of altering beliefs is known as conceptual change (Posner, Strike, Hewson, & Gertzog, 1982). Reflection, in the form of weekly blogs, was used as a tool in the conceptual change process by providing time for the preservice teachers to examine conflict in ideas and examine new ideas (Heywood, 2007). Preservice teachers did overall recognize common approaches in mathematics and science teaching by the end of the methods classes. Besides the learning cycle approach, they also included the use of reasoning, concrete experiences, students making connections, and assessment for commonalities in teaching mathematics and science. It is hoped that this experience with common approaches helped set the stage for the preservice teachers in their science and mathematics teaching.

Impact of Beliefs and Prior Experiences

Teachers make decisions about teaching practices based on underlying beliefs and past experiences (Kelly, 2000; Manouchehri, 1997). Although a few students said that hands-on, inquiry-based teaching, or the learning cycle were ways to approach teaching science and math, their blogs reflected contrasting beliefs about how science and mathematics should be approached. The participants shared their school experiences in the blogs. Some blogs would refer to hands-on learning. Then within the same blog or the next blog they would describe a teaching episode which was more traditionally oriented and focused on right answers rather than conceptual understanding. Those few, even with learning cycle lessons, would focus on whether or not students came up with right answers. Their beliefs impacted their decisions in how they implemented the lessons (Ball, 1991; Chick, 2007; Davis & Petish, 2005). The participants' school experiences interfered with their teaching practice and made it difficult for a few of them to be completely committed to the use of the learning cycle for mathematics teaching (Gee et al., 1996).

Research based materials were used for the lessons. However, curricula materials alone do not ensure a reform based practices (Battista, 1999; Huang, 2000). Battista (1999) found that even with reform based materials that teachers could potentially distort the ideas in the materials if the teacher had misconceptions. The variety of responses from students when given the same curriculum "…provides evidence of the interplay between curriculum as designed and curriculum as 'wrapped' around the ongoing action and interaction of students and teacher" (Cannizzaro & Menghini, p. 376, 2006). For preservice teachers in a methods course they are beginning to understand the "ongoing action" of teaching. Preservice teachers were using an approach which was unfamiliar to them and expected to use it at the same time in their field placements. Curricular materials were also unfamiliar in nature and goal. For elementary preservice teachers, who learn to teach multiple subjects, this could be a daunting task. Using the learning cycle approach in both science and mathematics can then provide a consistency and familiarity for preservice teachers to focus on their practice.

Issues with Inquiry

Inquiry-based teaching involves the exploration of students around a central idea, formulation of questions, investigations to answer the questions, and reflection of learned ideas (Morrison, 2008; Tracy, 1999). Some of the preservice teachers believed they were teaching inquiry-based lessons. Their descriptions of how they promoted inquiry were quite revealing. They held a naïve view of an inquiry-based approach. Gyllenpalm, Wickman, and Holmgren (2010) similarly found that teachers were "conflating *methods of teaching* with *methods of inquiry* [*sic*]" (p. 1151). They did not have a clear understanding of inquiry and the processes students should undergo in an inquiry-based lesson. Their reflections demonstrated that they did not have a deep understanding of what inquiry or problem solving means. Therefore, it can be inferred that they did not have a deep understanding of the learning cycle as an inquiry-based teaching approach. It was clear form their responses that they wanted to teaching inquiry-embedded lessons. For elementary preservice teachers, conceptions of inquiry may need to be explored more in methods classes to help them develop a clear understanding of how to fully implement inquiry-embedded approaches, such as the learning cycle.

Implications

Focusing on common approaches in mathematics and science helped many of the preservice teachers in this study to recognize the importance of an active learning environment. Evidence of preservice teacher development from the data indicated that a majority of the preservice teachers, who entered the methods class with expanded of progressive views of the use of tools, processes, and pedagogical approaches, deepened their conceptions throughout the semester. However, there were a few who entered the methods class with naïve or traditional views of teaching science and mathematics and had difficulty accepting new methods of teaching. Hill (1997) similarly found that elementary preservice teachers initially held an instrumental view of mathematics: mathematics as a set of memorized formulas and rules. This indicates a need for support for those students who initially hold naïve or traditional views of what it means to teach science and mathematics. Tasks in the methods class and careful placement with strong reform-minded mentors in the field may help them in their teacher development.

This study did use common approaches to mathematics and science through the learning cycle as a means of preparing future elementary teachers to teach science and mathematics. A majority of the preservice teachers recognized common approaches to teaching science and mathematics through the use of the learning cycle. Some focused more on certain aspects of the learning cycle than other aspects. The exploration and engagement aspects were appealing to preservice teachers. They wanted students to be engaged in learning. The exploration aspect of the learning cycle also fit in with their idea of hands-on learning. This partial understanding of the learning cycle can be expected with novice teachers learning how to teach. As preservice teachers enter the field it is important to provide coaching and support of reform-based approaches.

Participants' ideas about common approaches to mathematics and science changed for most of the participants. Learners moved from seeing science and mathematics as completely separate to being able to provide concrete examples from field experiences that articulated common approaches of science and mathematics in the elementary classroom. Findings indicated that purposeful planning and design of science and mathematics methods courses can yield changes in development of thinking about the teaching of mathematics and science. Additional studies are needed to examine if and how preservice teachers articulate common approaches to mathematics and science beyond the methods classes.

References

Abraham, M. R., & Renner, J. W. (1983). *Sequencing language and activities in teaching high school chemistry: A report to the National Science Foundation*. Washington, D.C.: National Science Foundation. (ED241267)

Akerson, V. L. (2005). How do elementary teachers compensate for incomplete science content knowledge? *Research in Science Education*, *35*(2-3), 245-268. Retrieved from http://www.eric.ed.gov

Akerson, V. L., & Donnelly, L. A. (2008). Relationship among learner characteristics and preservice elementary teachers' views of nature of science. *Journal of Elementary Science Education*, *20*(1), 45-58. Retrieved from http://www.eric.ed.gov

American Association for the Advancement of Science [AAAS] (1993). *Benchmarks for science literacy*. Retrieved from http://www.project2061.org/ publications/bsl/online/ index. php?txtRef =&txtURIOld=%2Fpublications %2Fbsl %2Fonline %2Fbolintro%2Ehtm

Atkin, J. M., & Karplus, R. (1962). Rebuilding the science program. *The Science Teacher*, *29*(5), 45-51.

Battista, M. T. (1999). The mathematical miseducation of America's youth. Phi Delta Kappan, 80(6), 424. Retrieved from http://search.ebscohost.com

Beeth, M. E., & McNeal, B. (1999). *Co-teaching mathematics and science methods course*. Retrieved from ERIC database. (ED443666)

Bleicher, R.E. (2006). Nurturing confidence in preservice elementary science teachers. *Journal of Science Teacher Education*, *17*(6), 165-187.

Boddy, N., Watson, K., & Aubusson, P. (2003). A trial of the 5Es: A referent model for constructivist teaching and learning. *Research in Science Education, 33*(1), 27-42. Retrieved from http://search.ebscohost.com

Bybee, R.W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Cardak, O., Dikmenli, M., & Saritas, O. (2008). Effect of 5E instructional model in student success in primary school 6th year circulatory system topic. *Asia-Pacific Forum on Science Learning and Teaching*, 9(2), Retrieved from http://search.ebscohost.com

Chick, H. L. (2007). Teaching and learning by example. In J. Watson & K. Beswick (Eds.) *Mathematics: Essential Research, Essential Practice. Volumes 1 and 2. Proceedings of the 30th Annual Conference of the Mathematics Education Research Group of Australasia, Adelaide, SA* (pp. 3-21). Mathematics Education Research Group of Australasia. Retrieved from http://www.eric.ed/gov

Clark, I. (2003). Soils ain't soils. *Investigating: Australian Primary and Junior Science Journal*, *19*(4), 13-16. Retrieved from http://search.ebscohost.com

Common Core State Standards Initiative. (2010). *Common core standards initiative standards-setting considerations*. Retrieved from http://www.corestandards.org/ assets/Considerations.pdf

Conference Board of the Mathematical Sciences [CBMS]. (2001). *The mathematical education of teachers* (Vol. 11). Providence, Rhode Island: American Mathematical Society.

Davis, E., & Petish, D. (2005). Real-world applications and instructional representations among prospective elementary science teachers. Journal of Science Teacher Education, 16(4), 263-286. doi:10.1007/s10972-005-8892-4

EDC Science Education. (2003). *Insights*. Dubuque, IA: Kendall/ Hunt Publishing.

Ergin, I., Kanli, U., & Unsal, Y. (2008). An example for the effect of 5E model on the academic success and attitude levels of students': "Inclined projectile motion". *Turkish Science Education*, *5*(3), 47-59. Retrieved from http://search.ebscohost.com

Fuller, R. A. (1996, October). *Elementary teachers' pedagogical content knowledge of mathematics*. Paper presented at the Mid-Western Educational Research Association Conference, Chicago, Il. Retrieved from ERIC database. (ED401270)

Gee, C. J., Boberg, W. S., & Gabel, D. L. (1996, April). *Preservice elementary teachers: Their science content knowledge, pedagogical knowledge, and pedagogical content knowledge*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, St. Louis, MO. Retrieved from ERIC database. (ED393702)

Glaser. B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Piscataway, NJ: Aldine Transaction.

Goodnough, K., & Nolan, B. (2008). Engaging elementary teachers' pedagogical content knowledge: Adopting problem-based learning in the context of science teaching and learning. *Canadian Journal of Science, Mathematics & Technology Education*, *8*(3), 197-216. doi:10.1080/14926150802315130

Gyllenpalm, J., Wickman, P-O., & Holmgren, S-O. (2010). Teachers' language on scientific inquiry: Methods of teaching or methods of inquiry? *International Journal of Science Education*, *32*(9), 1151-1172. Retrieved from http://search.ebscohost.com/

Haefner L. A., & Zembal-Saul, C. (2004). Learning by doing? Prospective elementary teachers' developing understanding of scientific inquiry and science teaching and learning.

International Journal of Science Education, *26*(13), 1653-1674. Retrieved from http://search.ebscohost.com

Hampton, B., Odom, A. L, & Settlage, J.Jr.. (1995, April). *The development and application of a diagnostic test to assess teachers' understanding of the learning cycle*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, San Francisco, CA. Retrieved from ERIC database. (ED387333)

Hanuscin, D. L., & Lee, M. H. (2008). Using the Learning Cycle as a Model for Teaching the Learning Cycle to Preservice Elementary Teachers. *Journal of Elementary Science Education*, *20*(2), 51-66. Retrieved from http://www.eric.ed.gov

Heywood, D. S. (2007). Problematizing science subject matter knowledge as a legitimate enterprise in primary teacher education. *Cambridge Journal of Education, 37*(4), 519-542. doi:10.1080/03057640701705856

Hill, H. C., Blunk, M., Charalambous, C., Lewis, J., Phelps, G. C., Sleep, L., & Ball, D. L. (2008). Mathematical knowledge for teaching and the mathematical quality of instruction: An exploratory study. *Cognition & Instruction, 26*(4), 430-511. Retrieved from http://search.ebscohost.com

Hill, L. (1997). Just tell us the rule: learning to teach elementary mathematics. *Journal of Teacher Education*. *48*(3), 211-222. Retrieved from http://search.ebscohost.com

Huang, H-M. E. (2000, August). Investigating of teachers' mathematical conceptions and pedagogical content knowledge in mathematics. Paper presented at the Working Group for Action Mathematics Education in Pre and Primary School, Makuhari, Japan. Retrieved from http://www.nku .edu/~sheffield/edithpbyd3.html

Illinois Central College. (1979). *DOORS Project: Development of operational reasoning skills.* Retrieved from ERIC database. (ED203775)

Interstate Teacher Assessment and Support Consortium [INTASC] (n.d.). *The INTASC standards*. Retrieved from http://www.wresa.org/Pbl/ The%20INTASC% 20 Standards%20overheads.htm

Justi, R., & van Driel, J. (2005). The development of science teachers' knowledge on models and modeling: promoting, characterizing, and understanding the process. *International Journal of Science Education*, *27*(5), 549-573. Retrieved from http://search .ebscohost.com

Kelly, J. (2000). Rethinking the elementary science methods course: A case for content, pedagogy, and informal science education. *International Journal of Science Education, 22*(7), 755-777. Retrieved from http://search.ebscohost.com

Kind, K. K. (1999). *Dialogue on early childhood science, mathematics, and technology education: First experiences in science, mathematics, and technology*. Retrieved from http://www.project2061.org/publications/earlychild/online/experience/ lind.htm

Kistler, B. (1997, November). *Mathematics Courses for the Prospective Teacher*. Paper presented at the Annual Conference of the American Mathematical Association of Two-Year Colleges, Atlanta, GA. Retrieved from ERIC database. (ED418926)

Kratochvil, D. W., & Crawford, J. J. (1971). *Science curriculum improvement study developed by the Science Curriculum Improvement Project*. (AIR-21900-11-71-TR-4). Washington, D.C.: Office of Program Planning and Evaluation. (ED058102)

Lawrence Hall of Science. (2003). *Full option science system* (FOSS). Nashua, NH: Delta Education.

Lawson, A. E., Abraham, M. R., & Renner, J. W. (1989). *A theory of instruction: Using the learning cycle to teach science concepts and thinking skills*. Retrieved from http://www.eric.ed.gov

Lindgren, J., & Bleicher, R. E. (2005). Learning the learning cycle: The differential effect on elementary preservice teachers. *School Science and Mathematics, 105*(2), 61-72.

Liu, T.-C., Peng, H., Wu, W.-H., & Lin, M.-S. (2009). The effects of mobile natural-science learning based on the 5E learning cycle: A case study. *Educational Technology & Society*, *12* (4), 344-358. Retrieved from http://search.ebscohost.com

Lonning, R. A., & DeFranco, T. C. (1994). Development and integration of an integrated mathematics/science preservice elementary methods course. *School Science and Mathematics, 94*(1), 18-25.

Lonning, R. A., DeFranco, T. C., & Weinland, T. P. (1998). Development of theme-based, interdisciplinary integrated curriculum: A theoretical model. *School Science and Mathematics, 98*(6), 312-318.

Manouchehri, A. (1997). School mathematics reform: Implications for mathematics teacher preparation. *Journal of Teacher Education*, *48*(3), 197-210. Retrieved from http://search.ebscohost.com

Marek, E. A. (2008). Why the learning cycle? *Journal of Elementary Science Education, 20*(3), 63-69. Retrieved from http://search.ebscohost.com

Marek, E. A., & Cavallo, A. M. (1997). *The learning cycle: Elementary school science and beyond.* Portsmouth, NH: Heinemann.

Marek, E. A., Laubach, T. A., & Pedersen, J. (2003). Preservice elementary school teachers' understandings of theory based science education. *Journal of Science Teacher Education, 14*(3), 147-159. Retrieved from http://search.ebscohost.com

Marek, E. A., Maier, S. J., & McCann, F. (2008). Assessing understanding of the learning cycle: The ULC. *Journal of Science Teacher Education*, *19*(4), 375-389. Retrieved from http://search.ebscohost.com

McGinnis, J., Kramer, S., & Watanabe, T. (1998, April). *A longitudinal assessment of teacher candidates' attitudes and beliefs in a reform-based mathematics and science teacher preparation program*. Paper presented at the Annual Meeting of the National Association of Research in Science Teaching, San Diego, CA. Retrieved from ERIC database. (ED421348)

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco, CA: Wiley & Sons.

Molina, D., Hull, S., Schielack, J., & Education, T. (1997). *Guidelines for the Mathematical Preparation of Prospective Elementary Teachers*. Retrieved from ERIC database. (ED 436370)

Morrison, J. (2008). Individual inquiry investigation in an elementary science methods course. *Journal of Science Teacher Education*, *19*(2), 117-134.

National Commission on Excellence in Education [NCEE]. (1983). *A nation at risk: The importance of educational reform*. Retrieved from http:www.ed.gov/pubs/ NatAtRisk/index.html

National Council of Teachers of Mathematics [NCTM]. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (1991). *Professional standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (1995). *Assessment standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (2006). *Curriculum focal points for prekindergarten through grade 8 mathematics: A quest for coherence*. Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (2009). *Focus in high school mathematics: Reasoning and sense-making*. Reston, VA: Author.

National Research Council [NRC]. (1989). *Everybody Counts. A report to the nation on the future of mathematics education.* Washington, DC: National Academy Press.

National Research Council [NRC]. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council [NRC], (2001). *Adding it up: Helping children learn mathematics*. Mathematics Learning Study Committee, J. Kilparic, J. Swaford and J. Findell (Eds). Washington DC: National Academy Press.

National Science Board [NSB] (2004). *An emerging and critical problem of the science and engineering labor force: A companion to Science and Engineering Indicators 2004*. Retrieved from http://www.nsf.gov/statistics/nsb0407/

National Science Resources Center. (2003). *Science technology for children*. Burlington, N.C.: Carolina Biological Supply Co.

National Science Teachers Association. (2003). *Standards for science teacher preparation*. Retrieved from http://www.nsta.org/pdfs/NSTAstandards2003.pdf

Ören, F., & Tezcan, R. (2009). The Effectiveness of the Learning Cycle Approach on Learners' Attitude toward Science in Seventh Grade Science Classes of Elementary School (English). *Ilkogretim Online, 8*(1), 103-118. Retrieved from http://search.ebscohost.com

Park Rogers, M. A. & Abell, S. K. (2008). The design, enactment, and experience of inquiry-based instruction in undergraduate science education: a case study. *Science Education, 92*(4), 591-607. Retrieved from http://search.ebscohost.com

Partnership for 21st Century Skills (2009). *P21 Framework definitions document*. Retrieved from http://www.p21.org/documents/P21_Framework_Definitions.pdf

Pearson Education (2007). *Investigations in number, data, and space*. Glenview, Ill: Scott Foresman

Plonczak, I. (2010). Videoconferencing in math and science preservice elementary teachers' field placements. *Journal of Science Teacher Education, 21*(2), 241-254. Retrieved from http://search.ebscohost.com

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66(2), 211-227.

Renner, J. W., & Lawson, A. E. (1973). Piagetian theory and instruction in physics. *The Physics Teacher*, *11*(3), 165-169.

Schmidt, L. (2008). How we don't learn. *Leadership, 38*(2), 10-14. Retrieved from http://search.ebscohost.com

Settlage, J. (2000). Understanding the learning cycle: Influences on abilities to embrace the approach by preservice elementary school teachers. *Science Education*, *84*(1), 43-50. Retrieved from http://www.eric.ed.gov

Skemp, R. R. (1976). Relational understanding and instrumental understanding. *Mathematics Teaching, 7*, 20-26.

Shapiro, S. (1983). Mathematics and reality. *Philosophy of Science, 50*(4), 523-548. Retrieved from EDS Foundation Index.

Simon, M. A. (1992, April). *Learning mathematics and learning to teach: Learning cycles in mathematics education.* Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA. Retrieved from ERIC database. (ED349174)

Soomor, A. Q., Qaisrani, M. N., Rawat, K. J., & Mughal, S. H. (2010). Teaching physics through learning cycle model: An experimental study. *Journal of Educational Research*, *13*(2), 5-18.

Steen, L. A. (1990). *Science and mathematics education: Similarities and differences*. Retrieved from http://www.stolaf.edu/people/steen/Papers/similarities.html

Stuessy, C. L. (1993). Concept to application: Development of an integrated mathematics/science methods course for preservice elementary teachers. *School Science and Mathematics, 93*(2), 55-62.

Stuessy, C. L., & Naizer, G. L. (1996). Reflection and problem solving: Integrating methods of teaching mathematics and science. *School Science and Mathematics, 96*(4), 170-177.

Tal, R. T., Dori, Y. J., Keiny, S., & Zoller, U. (2001). Assessing conceptual change of teachers involved in STES education and curriculum development: The STEMS project approach.

International Journal of Science Education, 23(3), 247-262. Retrieved from http://search.ebscohost.com

Taylor, C. (2009). *The effects of a combined mathematics content/methods course involving Learning Cycles on preservice elementary teachers' beliefs about the nature, teaching and learning of mathematics*. Ed.D. dissertation, Temple University, United States-Pennsylvania. Retrieved from Dissertations & Thesis: A&I. (Publication No. AAT 3344406).

Tracy, D. M. (1999). SSMiles. *School Science and Mathematics, 99*(7), 400-408.

Urey, M., & Calik, M. (2008). Combining different conceptual change methods within 5E model: A sample teaching design of 'cell' concepts and its organelles. *Asia-Pacific Forum on Science Learning and Teaching*, *9*(2), 1-15. Retrieved from http://www.eric.ed.gov

Walker, C. L., McGill, M. T., Buikema, A. L., & Stevens, A. M. (2008). Implementing inquiry-based learning in teaching serial dilutions. *Journal of College Science Teaching, 37*(6), 56-61. Retrieved from http://www.eric.ed.gov

Weld, J., & Funk, L. (2005). "I'm not the science type": Effect of an inquiry biology content course on preservice elementary teachers' intentions about teaching science. *Journal of Science Teacher Education*, *16*(3), 189-204. Retrieved from http://www.search.ebscohost.com

Williams, S. R., & Baxter, J. A. (1996). Dilemmas of discourse-oriented teaching in one middle school mathematics classroom. *The Elementary School Journal, 97*(1), 21-38.

Withee, T., & Lindell, R. (2006). Different views on inquiry: a survey of science and mathematics methods instructors. *AIP Conference Proceedings, 818*(1), 125-128. doi: 10.1063/1.2177039

Wong, K. K., Guthrie, J. W., & Harris, D. N. (2003). A Nation At Risk: A 20 year reappraisal. *Peabody Journal of Education*, v 79. Boca Raton, Fl: Taylor and Frances Group.

Yin, R. K. (2009). *Case study research: Design and methods*. (4th ed.). Thousand Oaks, CA: Sage Publications.

Zambo, R., & Zambo, D. (2007). Mathematics and the learning cycle: How the brain works as it learns mathematics. *Teaching Children Mathematics*, *14*(5), 265-270.

Zull, J. E. (2002). *The art of changing the brain: Enriching teaching by exploring the biology of learning*. Sterling, VA: Stylus Publications.

Appendix A

Pre-Test

1. How is teaching math like teaching science? What is similar and what is different?

2. How would concrete tools/experiences play a role in a science lesson? Give examples.

3. How would concrete tools/experiences play a role in a math lesson? Give examples.

4. Name and describe a few teaching strategies or approaches used to teach science for meaningful understanding.

5. Name and describe a few teaching strategies or approaches used to teach math for meaningful experiences.

Appendix B

Post-Test

1. How is math like teaching science? What is similar and what is different?
2. How would concrete tools/experiences play a role in a science lesson? Give examples.
3. How would concrete tools/ experiences play a role in a math lesson? Give examples.
4. A. Name and describe a few teaching strategies pr approaches used to teach science for meaningful understanding.

   B. Name and describe a few teaching strategies or approaches to teach math for meaningful understanding.
5. A. Think back to a science lesson that you taught this summer and briefly describe it.

   B. How do you think it met effective practice approaches to teaching? Explain.
6. A. Think back to a math lesson that you taught this summer and briefly describe it.

   B. How do you think it met effective practice approaches to teaching? Explain.
7. How has the blog helped you in your development of…

   A. Ideas about teaching science?

   B. Ideas about teaching math?

   C. Similarities between the teaching of math and science?

Appendix C

Weekly Blogs

Week 1: Why is following a Learning Cycle so important in teaching science? Won't more traditional approaches such as giving information first to students, such as in reading the textbook, completing worksheets, and writing notes/definitions work just as well? Why not? I am not convinced!

Week 2: We have learned about inquiry and the associated process skills for teaching science through 'doing science'. We have learned that the Learning Cycle for planning and teaching a series of lessons is 'best practice' to maximize student engagement and understanding of the science we are teaching - often called a "hands-on, minds-on" approach. So, how does the Science-Technology-Environment-Society piece fit into all of this? What really is it anyway? How does it work, and is it important in my science teaching? Please explain and help clear up my confusion.

Week 3: So, this week you had the chance to finally practice teach about either ecological or technological ideas to kids, and followed some portion of the Learning Cycle to do it! (whether an 'exploration' activity to first develop students' common understandings OR an 'elaboration' activity to get them to apply their previous learning to a new situation or use). Also, assessment was on everyone's mind. So, how did you assess your students' attitudes, understanding, or performance in your lesson this week? Do you feel your assessment strongly aligned with your learning objective(s)? Was it authentic enough? Why is assessment so important anyway? Share your thoughts about your thinking and how you are feeling about assessment.

Week 4: This week we have been doing many hands-on activities in our FOSS Earth Materials kit curriculum. All of the hands-on activities have been pretty fun, or at least interesting. Most of us really believe that ‘hands-on’ is the best way to go in teaching science, but is there more to it? What do you think? Are all hands-on activities equal? Is hands-on best no matter what you do, when you do it, or how you do it? Explain to me your thinking now about ‘hands-on’ activities in science to best help student learning. I know that you can help me understand this approach better and are pretty knowledgeable about how to do it best.

Week 5: Kids and stuff everywhere! Inventing and building and Newton’s Laws of Motion can certainly seem to be unruly in the classroom, but is this O.K.? Taking kids outdoors to learn about science in nature also has its own planning and managing hurdles, but is it worth it? Even in doing the state of Alabama’s science teaching in the classroom (AMSTI) with kits, there is a level of uncertainty and messiness with kids and materials ‘in motion’, but it seems to work. How are you now feeling about these issues? Where do you begin personally in your future classroom? What is your current thinking and your plan?

Week 6: Think about the Learning Cycle. Explain how the Learning Cycle pertains to the teaching and learning of mathematics. Support with examples. Then respond to two other people's responses.

Week 7: So far in class we have discussed inquiry in mathematics, assessing mathematical understanding, developing number sense, and participating in tasks to develop our own mathematical knowledge. Think about all we have talked about, experienced for ourselves, and experienced with students. Explain which part of the Learning Cycle you find to be the most important in developing a true understanding of mathematics and why. Support with examples of your own experiences or mathematics field experiences.

Week 8: In class we have been learning about how to assess and different types of assessment. Think about one of your math teaching experiences this semester. How did you determine student understanding of the topic? Be specific. Support with examples. Based on your assessment what judgments and decisions will you have to make about teaching/learning? Would you teach the lesson differently if you taught it again? Be specific. Support with examples.

Week 9: We have used concrete materials in class and with students in lab. I want you to think about the role that concrete experience plays in learning. Think of an instance in which concrete experiences played a role in your own learning of mathematics. Describe that learning experience. Describe how you have used concrete experience in one teaching lesson this term.

Week 10: Think about the two consecutive lessons you taught this week. What growth did you see in your students' understanding of the topic? What role did concrete experience play in your lessons? How did you promote inquiry?

CHAPTER 5: ELEMENTARY STUDENT TEACHERS' CONCEPTIONS AND USE OF TOOLS, PROCESSES, AND APPROACHES FOR MATHEMATICS TEACHING

Abstract

This study focused on two elementary student teachers' thinking and practice in the use of tools for conceptual development, processes for meaningful learning, and pedagogical approach for teaching mathematics. The study took place during their student teaching experience and is a continuation from a study that took place during the participants' science and mathematics methods class. The nature of the students' understandings was examined through several data sources: observations, open-ended questionnaire, final reflection, and researcher field notes of practice. Data sources from the methods class were compared with data from the student teaching. The case studies for "Jane" and "Kate" are presented. Jane and Kate are pseudonyms. Jane and Kate participated in a jointly enrolled science and mathematics methods class that used the learning cycle approach as a method for teaching science and mathematics. The cases of Jane and Kate were selected because of their different development in the methods courses. Kate thought of approaching mathematics using real-world mathematics. Her conceptions of tools for math were manipulatives for teaching real-world concepts, such as time and money. Processes were controlled in a teacher led lesson. Her approach for math, initially, was the teacher explained and students worked problems. Jane thought of mathematics, initially, as being a subject that should have a hands-on approach. She wanted students to see for themselves and figure out the mathematics. However, by the end of the methods course they both

conceived of science and mathematics as being taught with the learning cycle approach but in different ways. Jane thought the learning cycle would help make mathematics meaningful and make students actively involved in learning mathematics. Kate considered the exploration and evaluation phases of the learning cycle to be important in teaching mathematics. She believed that the exploration phase helped students construct knowledge. She believed evaluation was important in order for the teacher to see the students' levels of understanding. Implications for preservice teachers and teacher educators are provided.

Introduction

Preservice teachers are often products of a traditional classroom that focuses on repetition and memorization with little attention to understanding (Taylor, 2009). Elementary preservice teachers enter the undergraduate program with beliefs about mathematics that have been shaped by those experiences (Manouchehri, 1997). Examining the mathematics standards documents reveals goals that are at odds with the traditional approach to teaching mathematics: to move away from memorization and rote learning and instead to focus on conceptual understanding (Kind, 1999; National Council of teachers of mathematics (NCTM), 2000; Steen, 1990). The standards documents promote mathematics and scientific literacy; being able to ask, find, and determine answers (Kind, 1999; NCTM, 2000; National Research Council (NRC), 1996; Steen, 1990). Since many of today's preservice teachers lack a model of standards-based reform teaching from school experiences (Conference Board of Mathematical Sciences (CBMS), 2001), the use of the same reform-based approach to teaching in mathematics and science, like the learning cycle, could help in their understanding and teaching. In addition, the use of inquiry processes embedded within the learning cycle for both mathematics and science is another area of commonality that requires further study. A lack of research exists on the development of elementary preservice teachers and their thinking about use of inquiry as processes in mathematics as they progress through their teacher preparation program.

Common inquiry processes for science and mathematics are founded in the natural curiosity of a child (Neal, 1962). This natural curiosity causes children to pose questions about phenomena around them and seek out the answers to those questions (Neal, 1962). Inquiry is often historically associated with science (Neal, 1962). Yet, inquiry is inherent in mathematics as well. Children seek to understand numbers and patterns in the world around them. Young children explore science and mathematics concepts as a means of understanding (Hoffer, 1993; Speilman & Lloyd, 2004; Zull, 2002). The physical experience enables them to develop abstract thinking and make generalizations (Renner & Lawson, 1973). Tools, therefore, become a means for children to explore and develop understandings. Tools in science are often thought of as materials and equipment used to answer and pose questions (Neal, 1962). Mathematics uses tools as well. Tools in mathematics for young children start off as objects to count, classify, or describe (NCTM, 2000). As children answer questions about science or mathematics concepts through exploration, they are involved in thinking processes. These processes help develop sense-making, reasoning and proof, and communication (NCTM, 2000).

However, the description of mathematics being taught from an inquiry oriented perspective, although a natural form of learning for children, is often not the approach taken by elementary mathematics teachers (Taylor, 2009). Mathematics is often reduced to a series of procedural problems or word problems to practice a procedure (Hill, 1997). Furthermore, tools may become a source of procedural focus as well, rather than a means of understanding mathematical relationships. The CBMS (2001) in their standards document determined that teacher preparation programs had the daunting task of preparing teachers with primarily traditional classroom experiences to teach in alternative ways. Using tools to foster processes and inquiry is, therefore, a challenging task for future educators (CBMS, 2001). They are not used to experiencing mathematics through inquiry and may associate mathematics with formulas and word problems (Hill, 1997).

Similarly, Interstate New Teacher Assessment and Support Consortium (INTASC) developed general standards for new teacher candidates (n.d.). The INTASC principles focus on teachers developing meaningful lessons using "tools of inquiry" and designing instruction to develop students' problem solving and critical thinking skills; teaching approaches also contradictive to traditional methods of teaching. Teacher education programs have to establish a process that allows preservice teachers opportunities to develop those recommended teaching skills (Manouchehri, 1997; Noori, 1994; Speilman & Lloyd, 2004) and understand the complex task of teaching (Grossman et al., 2009). Since new teachers may not understand the complexity of teaching, teacher preparation institutions face the challenge of helping novice teachers see the array of components that comprise teaching (Bolton, 1997; Grossman et al., 2009). Education programs have to take into account students prior experiences and provide experiences that allow the preservice teachers to shift or alter their belief system to envelop the ideologies of the program (Ball, 1988; Heywood, 2007; Kelly, 2000). Approaching science and mathematics from a common pedagogical approach has been used as a means of helping preservice teachers deepen their understandings and make connections between the teaching of the two subjects (McGinnis & Parker, 1999).

Issue as Conceived in Study

Improvement of science, technology, engineering, and mathematics (STEM) education is of great importance today (Atkinson & Mayo, 2010). As the language of science (Shapiro, 1983;

Steen, 1990), a strong mathematical background is necessary for students to succeed in STEM fields. In order for students to be able to take the high level mathematics courses in high school to be eligible for STEM fields, they need a strong foundation in mathematics in the elementary grades. Teacher preparation programs are tasked in the preparation of elementary teachers to teach mathematics to build a strong foundation in their students (Manouchehri, 1997; Noori, 1994; Speilman & Lloyd, 2004). Teacher preparation programs implement content courses to help build content knowledge of teachers, design methods courses to teach the pedagogy of the subject, and place preservice teachers in a full-time teaching experience as the culmination of their program (Bales & Mueller, 2008). However, research on elementary preservice teachers and mathematics often focuses on their development within content courses (Alsup, 2003; Emenaker, 1996; Even et al., 1996; Gresham, 2007; McLeod & Huinker, 2007), methods courses (Lonning & DeFranco, 1994; Quinn, 1997; Stuessy, 1993), or student teaching (Clark, 2005; Johnson, 1980; Lubinski, Otto, Rich, & Jaberg, 1995; Philippou, 2003; van Es, 2009).

A few researchers have studied elementary preservice teachers beyond just the content course or methods course (Castro, 2006; Lubinski et al., 1995; Wilcox, Schram, Lappan, & Lanier, 1991). Castro (2006) studied the way elementary preservice teachers conceived of curricular materials for mathematics teaching in a mathematics content course and subsequent mathematics methods course. Preservice teachers conceived of tools as learning tools or as instructional aids for the teacher. Lubinski et al. (1995) studied 6 elementary preservice teachers during mathematics methods class and student teaching. The authors determined that they could not determine the effect of the methods course on mathematics teaching during internship. Other factors that influenced the preservice teachers during internship included the cooperating teacher, classroom environment, personal maturity, and depth of mathematical understanding. Wilcox et al. (1992) concluded, after observing beginning teachers through their preparation process, that teacher conceptions of teaching and learning influence instructional decisions.

Preservice teachers in this study were in science and mathematics methods classes which were taught with the learning cycle, an inquiry-embedded approach, see Chapter 4. Two semesters after the science and mathematics methods courses, preservice teachers entered their student teaching experience. Student teaching is 15 weeks of being in a classroom full-time. During the student teaching, the classroom teacher gradually releases all of the responsibilities of the classroom over to the student teacher. In order to ascertain how preservice teachers carried over practice of tools for conceptual development, processes for learning, and the learning cycle approach in mathematics into their student teaching, preservice teachers needed to be studied as they moved through the teacher preparation process.

Research Questions

Since integration of theory and practice continue to be important in teacher preparation (Fennell, 1993), research needs to be conducted as preservice teachers transition from teaching in a methods course through the student teaching experience (Jong & Brinkman, 1999). A lack of research exists on the development of elementary preservice teachers and their thinking about common pedagogical approaches as they progress through their teacher preparation program. Manouchehri (1997) called for researchers to conduct long term studies on change of preservice teachers and how this change is exhibited in teaching practices. Methods of inquiry in teaching science and mathematics share common processes for meaningful learning and use of tools for conceptual development (NCTM, 2000; NRC, 1996). This study intended to examine preservice teachers' conceptions of mathematics teaching in relation to common processes, tools, and pedagogical approaches while completing the student teaching experience. The question of this study was: How did preservice teachers put into practice in student teaching their thinking from the methods courses on tools for conceptual development, processes for meaningful learning, and pedagogical approaches to mathematics teaching?

Literature Review

Common Processes

Processes for meaningful learning are described in the *Principles and Standards for School Mathematics* (NCTM, 2000) and the *National Science Education Standards* (National Research Council (NRC), 1996). Process skills are also considered thinking skills (Sambs, 1991). These processes include problem solving, reasoning and proof, communication, connections, and representations (Goodnough & Nolan, 2008; Justi & van Driel, 2005; NCTM, 2000). Processes must be facilitated by the teacher in order for students to "make meaning of their world by logically linking pieces of their knowledge, communication and experiences" (Jaeger & Lauritzen, 1992, p.1). In mathematics students are asked to solve problems, reason about their answers and demonstrate proof, represent their work, and communicate their findings (NCTM, 2000). Similarly in science, students are expected to be able to ask questions and then find the answers to those questions, validate findings, explain their findings, and be able to evaluate the conclusions of others (NRC, 1996). Furthermore, in mathematics and science, students are expected to make connections or identify relationships between and among concepts and areas of study (NCTM, 2000).

Problem Solving. Problem solving is one of the processes common to science and mathematics teaching. "Problem solving means engaging in a task for which the solution is not known in advance" (NCTM, 2000, p. 52). For science, the problem solving process often occurs during scientific inquiry in which students are finding out the unknown (NRC, 1996). Whether called problem solving, as in mathematics, or a part of inquiry, as with science, students have to learn how to gather information, record collected data, and offer answers and explanations of those answers (NCTM, 2000; NRC, 1996). Since not all problems are simple, problem solving causes the learner to wrestle with alternative solutions and take risks in thinking (Manouchehri, 1997, NCTM, 2000). Thinking about alternatives in solutions allows the learner to expand problem solving skills and gain insight into the content that can be reapplied in later situations (Manouchehri, 1997). Swartz (1982) expounded on the importance of problem solving using a variety of strategies to gain understanding. The problem solving process, therefore, promotes the development of thinking skills (NCTM, 2000).

Problem solving often begins, for both science and mathematics, in problem posing (NCTM, 2000, NRC, 1996). Children have a natural curiosity about the world in which they live (NCTM, 2000). This natural curiosity leads them to question and explore the world around them. Students build knowledge through the problem solving process (Goodnough & Nolan, 2008; NCTM, 2000). Problem solving provides a means for teachers to create a mathematics and science classroom that fosters teaching through conceptual learning rather than rote memorization (Molina, Hull, Schielack, & Education, 1997; NCTM, 2000).

Reasoning and Proof. Reasoning and proof help students develop logical thinking that helps one decide if an answer makes sense. Students develop guesses or conjectures about concepts, experiments, or observations (NCTM, 2000; NRC, 1996). In mathematics, students note patterns. They use reasoning and proof processes to determine if the "patterns are accidental or if they occur for a reason" (NCTM, 2000, p. 56). Reasoning and proof includes the ability of students to use counterexamples to disprove a conjecture (Chick, 2007; NCTM, 2000). Similarly in science, students use reasoning and proof processes in experiments and tests to determine if the results are consistent or conditions that make the results different (NRC, 1996). Reasoning and proof are especially critical in science due to the nature of science requiring evidence of conclusions based on experiments and observations (NRC, 1996).

Communication. As students are involved in problem solving and reasoning and proof of a situation, communication becomes another common process that emerges. Communication involves all aspects of communication including talking, writing, and listening about the concept being learned (NCTM, 2000; NRC, 1996). Communication allows students to refine their thinking and cement ideas (Goodnough & Nolan, 2008; NCTM, 2000; Zull, 2002). Classroom discourse becomes a critical arena for students to share, question, and revisit ideas (NCTM, 2000). Students benefit from learning about the way other students in the class think about and solve problems (NCTM, 2000). Communication also aids students in the developing of more formal mathematical language (NCTM, 2000). Since science is based on experiments and observations, communication in science is important for students to express their understanding, make predictions, and develop conclusions of experiments and observations (Goodnough & Nolan, 2008; NRC, 1996). In mathematics communication becomes important as students present their proofs for other students in the classroom to understand the reasoning behind the proof (NCTM, 2000).

Connections. Connections allow students to have a deeper understanding of a concept (NCTM, 2000; Zull, 2002). Connections can be made within topics, to other subjects, or to experiences (NCTM, 2000). Furthermore, connections help students to link concepts rather than learn isolated facts (NCTM, 2000). In mathematics, students may complete a series of inquires investigating the relationship of the volume of three-dimensional figures with the same height and base. Their investigation will aid them to make connections between the two volumes to draw conclusions about the volume of cones and cylinders. In science, students may take their knowledge of what makes a simple circuit to make connections to series or parallel circuits.

Representations. As students solve problems in mathematics and science they rely on representations to express ideas (Davis & Petish, 2005; Justi & van Driel, 2005; NCTM, 2000). Representations are not only what occurs on paper, but what also occurs in the mind (NCTM, 2000; Zull, 2002). Symbols, diagrams, graphs, and images are examples of representations (NCTM, 2000; Posner, Strike, Hewson, & Gertzog, 1982). In science as students test a simple circuit consisting of a battery, a light bulb, and connecting wire, students represent on paper their various tests. Similarly, in mathematics, as students determine combinations of outfits they represent the combinations through colored squares or drawings labeled by their own invention. Concrete tools allow students to begin to develop more complex forms of representations (NCTM, 2000). However, there are situations in which representations may serve as an obstacle if the learner does not know how to interpret the representation (Heywood, 2007). For example, if students in a classroom did not understand how base 10 blocks represented the number system, this would be an obstacle in using the representations. Communication among students about their representations can serve as providing cohesiveness with the mathematical thinking and the representation of that thinking. Furthermore, representations allow students to relate concepts to the real world and are important in communication, reasoning and proof, and problem solving (NCTM, 2000).

Common use of Tools for Conceptual Development

Experiences impact the way students learn and understand (Hoffer, 1993; Speilman & Lloyd, 2004; Zull, 2002). Concrete tools offer opportunities for direct experiences and added opportunities for learning (Hoffer, 1993; Marek & Cavallo, 1997; Zull, 2002) as well as supporting real world mathematical and science situations (Jurdak & Shahin, 2001; NRC, 1996). The National Research Council (1996) recommended that students must have tools in order to be able to directly investigate scientific phenomena. Tools for developing concepts are often in the form of models (Justi & Gilbert, 2000). Learning aids in mathematics are known as manipulatives, and student use should precede symbolic notation (Sriraman & Lesh, 2007). Mathematics and science relies on representations to express ideas (Davis & Petish, 2005; Justi & van Driel, 2005; NCTM, 2000; NRC, 1996). Concrete tools allow students to begin to develop more complex forms of representations which allow students to relate concepts to the real world and are important in the processes of communication, reasoning and proof, and problem solving (NCTM, 2000).

Merely giving students concrete materials does not ensure that connections will be made or deep levels of understanding will be attained (Justi & Gilbert, 2000). When teachers plan lessons, choices are made as to the representations or models to be used in the lesson (Chick, 2007; Goodnough & Nolan, 2008). Teachers determine questions, explanations, and tasks involving the tool while keeping in mind the learning objective for the lesson (Chick, 2007; Goodnogh & Nolan, 2008). Teachers must provide a means for students to make connections from the experiences with concrete tools (Bleicher, 2006).

Tools become a helpful resource in science and mathematics for students to be able to reason and provide proof of their solution (NCTM, 2000; NRC, 1996). It is recommended that students use concrete materials as a means of investigating conjectures held about concepts (NCTM, 2000; NRC, 1996). Tools for mathematical calculations are often used in science as a means of providing evidence for the conjecture: measurement devices for time, length, capacity, temperature, and weight. Tools in mathematics for reasoning and proof may involve measurement devices but they might also be strings or numbers, calculations, or diagrams. For example, children in a science classroom may use a magnifying glass to observe organisms or objects to answer a question. Their observations then lead them to look for patterns or to list common features. This is very similar to students in a mathematics class examining and sorting pattern blocks to determine which ones fill a space. In both scenarios students are actively involved in problem solving with tools as a means of providing reasoning and proof to their conclusions.

Common Pedagogical Approaches

Focusing on processes and tools for conceptual development makes the learner an active part of the learning process. Educators have approached teaching based on the idea of active learning through the process of exploration, investigation, and articulation and have called this the learning cycle approach or learning cycle. The learning cycle offers a way of incorporating similar teaching methods of using tools for conceptual development (Chick, 2007; Fuller, 1996; Hill, 1997), discourse (Akerson, 2005; Heywood, 2007; William & Baxter, 1996), assessing student knowledge (Manouchehri, 1997; NCTM, 2000; NRC, 1996) inquiry-based teaching (Morrison, 2008; Manouchehri, 1997; NRC, 1996; Weld & Funk, 2005), and reflection (Bleicher, 2006; Hill, 1997; Manouchehri, 1997). Components of inquiry are evident in the learning cycle approach (Gee, Boberg, & Gabel, 1996; Tracy, 1999; Withee & Lindell, 2006). Inquiry-based teaching involves the exploration of students around a central idea, formulation of questions, investigations to answer the questions, and reflection of learned ideas (Morrison, 2008; Tracy, 1999). Furthermore, the learning cycle approach provides a framework for structuring inquiry-based lessons (Marek, Maier, & McCann, 2008; Marek & Cavallo, 1997). As a framework, the learning cycle provides a means for inquiry and its processes, problem solving, reasoning and proof, communications, and connections, to be applied. Within the learning cycle framework, tools serve as a means for conceptual development across all processes.

Although the learning cycle has its roots in the science field (Bybee, 1997; Atkin & Karlpus, 1962), the tenets align closely with the national mathematics standards. Similarly, Marek and Cavallo (1997) explained that the learning cycle could be used in mathematics for problem solving, and provided examples of learning cycle lessons to teach measurement and geometry concepts. In the engagement phase teachers have students focus on an event or problem (Bybee, 1997). This may be accomplished through a question, a situation or problem (Bybee, 1997; Marek et al., 2008). Teachers may even present a discrepant event as a means of engaging students (Marek et al., 2008; Tracy, 2003). Students then move into the exploration phase. Teachers have the responsibility of providing the materials, observing and ensuring students are conducting the experiment correctly, and interacting with students while students are collecting data (Marek, 2008). Physical experiences in the exploration phase are necessary (Bybee, 1997) and allow the learner to move beyond initial observations to generalizations (Renner & Lawson, 1973). In the explain phase, students are explaining what they discovered in the explore phase (Withee & Lindell, 2006). Once the students have an explanation for their experiences in the explore phase, the learning moves to the elaborate phase (Bybee, 1997). In this phase students are applying or extending what they learned to a new situation (Atkin & Karplus, 1962; Marek, 2008). Evaluation is the last phase but does not have to occur last because it can occur throughout the lesson (Bybee, 1997; Marek, 2008; NCTM, 2000).

Student Teaching and Mathematics

The student teaching experience is typically a fifteen week full-time teaching experience and is intended as a time to help new teachers solidify their practice. Novice teachers are expected to take what they learned about teaching from methods courses and put it into practice during the full-time teaching experience (Grossman et al., 2009). Preservice teachers learn the day-to day routines of being a teacher during the student teaching experience. This experience is affected by the culture and norms of the school in which it takes place (Cuenca, 2011). The cooperating teacher serves as the guide to help the student teacher with the norms of teaching (Feiman-Nemser & Buchmann, 1986). The context of the school and the norms of the classroom, established by the cooperating teacher, influence the work of the beginning teacher (Cuenca, 2011; Feiman-Nemser & Buchmann, 1986).

Inherently the culture of the school may clash with the philosophy of the student teacher and the preparation institution (Crawford, 2007). Some cooperating teachers are open to the student teacher teaching reform-based lessons (Philippou, Charalambos, & Leonidas, 2003). In other cases the traditional norms of the classroom inform the student teacher of the manner in which to teach mathematics (Lubinski et al., 1995). In the case of mathematics teaching, barriers may also arise in the use of tools for exploration (van Es & Conroy, 2009). Furthermore, Crawford (2007) noticed that skepticism of reform practices developed with student teachers during student teaching due to the culture clash of the assigned classroom and the university philosophy of teaching.

Preservice teachers, however, improve their mathematics teaching during internship in several ways. Clark (2005) observed preservice teachers modeling mathematical concepts effectively. Teacher candidates also developed skills in the selection and design of mathematics lessons (Johnson, 1980). Their teaching experiences helped them realize that sometimes they would have to digress from the lesson plan in order to meet students' mathematical needs (Clark, 2005; Lubinski et al., 1995). Likewise, student teaching allowed preservice teachers to teach hands-on lessons and design lessons that helped students make real world connections (Clark, 2005; Lubinski et al., 2005). Teacher candidates who did use more hands-on lessons and helped students make real-world connections also recognized students had a deeper understanding of the concepts (Clark, 2005).

Methodology

Case Selection

The cases were two elementary preservice teachers who had already participated in a study on conceptions of common approaches to teaching mathematics and science, and who were completing their student teaching. These two cases were selected because they were placed in schools and with teachers who had participated in a state-wide mathematics initiative. The student teachers had access to reform curricula and materials. The cooperating teachers gave them the freedom to design and implement their lessons as long as they met the given teaching objectives. Also, based on their methods course data, they represented two different ways of approaching mathematics. The result is the following case of “Jane” and “Kate”. Jane and Kate are pseudonyms.

Jane and Kate were in jointly enrolled science and mathematics methods courses two semesters before their student teaching. Teacher candidates completed science methods the first part of the semester and mathematics methods the second part of the semester. The purpose of the methods courses was to prepare the teacher candidates in methods and practice of teaching reform-minded science and mathematics. The learning cycle, with inquiry embedded, was the focus of both courses. It was used as a common approach to teaching both methods courses. Furthermore, Jane and Kate spent time in field placements during the science and mathematics methods class using the learning cycle as a framework. During the first five weeks of the semester they practiced teaching science in field placements using tools and fostering processes with the learning cycle approach. They continued to use tools and foster processes with the learning cycle approach when they moved into the mathematics portion of the methods course. At the beginning of the science and mathematics methods course, Jane and Kate appeared to have quite different conceptions of science and mathematics and how the two subjects should be taught. Jane conceived of tools, processes, and approaches for students to see and understand the mathematics. Kate conceived of tools and processes for real-life mathematics with a teacher directed approach. However, by the end of the methods courses they both described mathematics as being taught with the learning cycle approach but in different ways.

Context of the Study

Jane and Kate were both placed at the same school to complete their student teaching. The school is a rural school that is 80% Caucasian with about 50% of the students on free or reduced lunch. The teachers in the school had participated in ongoing state sponsored professional development for teaching reform-based mathematics and science. Since the teachers had participated in professional development institutes, *Investigations in Number, Data, and Space* (Pearson, 2007) kits, materials, and curricula were available for the teachers to use in teaching mathematics. The student teachers were placed under the supervision of a group of teachers within the school. The cluster teachers were responsible for the supervision, observation, and general guidance of the student teachers. The student teachers were placed with a single cooperating to learn the day-to-day operations of a classroom.

Jane was placed in a third grade self-contained classroom. She was responsible for teaching all subjects. She had eighteen students in her class. Kate was placed in a fourth grade classroom. The students in her class switched with two other fourth grade teachers. She was responsible for three mathematics classes. The students in the mathematics classes were assigned to a class based on their mathematics ability level. Students were considered to be low, medium, or high ability levels.

The study took place in the assigned classrooms of the student teachers. Being in the classroom environment allowed the researcher to acquire information firsthand, learn about the daily routines, and become well familiarized with the context of the learning environment for each preservice teacher involved in the study (Bogdan & Biklen, 1982; Glaser & Strauss, 1967; Hatch, 2002; Marshall & Rossman, 1995; Merriam, 1998). The researcher served as the primary investigator who attempted to record the phenomena, person, and/or interactions being studied and did not serve in any supervisory role (Hatch, 2002; Lancy, 1995). The researcher served as an instrument for data collection since the researcher's sense-making influenced what the researcher distinguished as important in the setting (Hatch, 2002; Merriam, 1998). The human factor also meant that bias was inherent in the observations and analyses due to the fact that a human collected, investigated, and made determinations based on a human's knowledge (Merriam, 1998).

For this study a case study approach was used (Hatch, 2002; Merriam, 1998; Stake, 2005) with a grounded theory approach to analysis (Charmaz, 2005). More specifically these were narrative case studies (Connelly & Clandinin, 1986). Connelly and Clandinin (1986) believed that the story of the teacher in context serves as a means of understanding. They posit that teachers themselves may gain new knowledge but that this knowledge may not be actually reflected in their practice. Furthermore, they suggest that the only way to understand a teacher's knowledge is to experience the knowledge in context. They believe that teacher knowledge is composed of experiences from personal and social contexts (Connelly & Clandinin, 1986).

The two weeks of full-time teaching required of student teachers was selected as the time to observe and collect data. In both cases the cooperating teachers provided the student teachers with a list of objectives to meet during the time frame. The student teachers were responsible for planning lessons, implementing lessons, and the daily routines of an elementary classroom. The student teachers had access to the curricular materials for that grade. Jane was observed teaching six times and Kate was observed teaching five times during that time period. Lesson plans were provided at the beginning of the week.

Data Collection

Data sources included six teaching observations for Jane and five teaching observations of Kate, follow-up interviews after each observation (see Appendix A), lesson plans, and an open-ended final reflection (see Appendix B). The lesson plans served as a means of seeing at a glance if the observed lesson was what the preservice teacher had planned. The follow-up discussions were important to gain information on the student teacher's goals for the lesson and decisions that went into the structure and implementation of the lesson. The final reflection was similar to the final reflection from the methods course and provided another data source for the preservice teacher to reflect on their teaching experiences.

The researcher recorded observations of mathematics lessons taught by the student teachers in the cases presented (Hatch, 2002). Notes that were taken included the arrangement of the rooms, the types of materials used in the lesson, questions the teacher asked, how much time students spent on different parts of a lesson, questions and answers students presented, and overall impressions of the lessons. After observing and taking notes during the lessons, the researcher would discuss the lesson with the student teacher. Discussions followed each observed teaching episode. Discussions included not only questions pertaining to the study but the researcher referred back to information from the methods courses. Discussions began with a general question about how did they think the lesson went. This opening question was used as a means to have the student teacher begin to reflect on the teaching episode. Questions in the discussion that followed referred back to the common teaching approaches used in the science and mathematics methods classes (see Appendix A). Those questions inquired about the learning cycle as a common pedagogical approach, the role of inquiry as a means of fostering processes, and how they used tools to develop the concept. The researcher would pose the question, record the response, and read it back to the student teacher. Additional comments that were made or revisions from the student teacher were recorded.

As their mathematics methods instructor, the researcher was able to discuss and recall elements of the methods courses as a means of helping the preservice teachers connect methods course with student teaching. After the general discussion questions (see Appendix A) the researcher would then begin to probe the preservice teachers to reflect on the observed lesson and ascertain the development they were trying to achieve as the week progressed. Based on their responses more questions were asked to gauge what they remembered from methods class. This allowed the researcher to mention materials or lessons that the student teachers may have forgotten about since a semester had lapsed between methods courses and student teaching. It also provided the student teachers with time to ask questions about tools, teaching approaches, student management, or organization of lessons. The researcher was intrinsically involved in helping the preservice teachers make connections to methods class through the debriefings that occurred after the teaching episodes. The researcher served as part of the teacher development process by focusing preservice teachers on ideas from the methods course including the learning cycle as an inquiry embedded approach, use of tools, and development of processes.

Data Analysis

Triangulation of data was used to ensure trustworthiness of the study (Yin, 2009). Triangulation relied on checking the information throughout various data sources. The constant comparative method (Glaser & Strauss, 1967) was used to find conceptions of mathematics and science teaching that emerged from the varying data sources. For each student teacher each interview, observation, lesson plan, final summation and memo was coded based on the research questions (Merriam, 1998). Information that was striking to the researcher in regard to preservice teachers' thinking about how they linked ideas in practice across disciplines was noted for each data source (Merriam, 1998). Codes were determined based on words or phrases from the participants, conclusions from the researcher, or connections to existing research (Glaser & Strauss, 1967; Merriam, 1998). Data about tools, use of tools, plans involving tools and so forth were labeled with the code of T. Data about processes that took place during the lesson were labeled with a P. Information about pedagogical approaches was labeled with a PA. Data that referred to the learning cycle was coded as LC. Lesson plans were labeled as LP, observations as O, follow-up interviews as FI, and final reflection as FR. For example, Jane's lesson plan for the first observation stated "Review of measuring to the nearest inch" (J, LP, 4/14). In the observed lesson Jane did review how to measure to the nearest inch using items on the overhead projector. These statements were both coded as "tools for measurement". Since Jane led the students step by step through a series of measurements this was also coded as "teacher directed". During the follow-up discussion when asked "In what ways did you use tools for conceptual development" Jane said "Showing them the different items on the projector" (J, FI, 4/14). This was coded as "tools for measurement-teacher directed". Then the first teaching observation and follow-up discussion was read through again for the case to determine if commonalities existed that could group some of the items together or if other generalizations became apparent (Merriam, 1998). Comparing lesson plans to teaching observations to follow-up discussions provided verification of the data. For example, the researcher could see that in the lesson plan the students would be measuring, the students somewhat measured in the teaching episode, and in the follow-up discussion the student teacher confirmed that the lesson did not go as she had planned. This process of constant comparison continued for each set of data for each case (Charmaz, 2006; Glaser & Strauss, 1967; Merriam, 1998). Once all of the coding had been completed a table was constructed for each participant. All of the codes for tools, processes, and approaches were placed in separate sections with the information in each section placed in chronological order. Codes were then regrouped to fit like items together (Saldana, 2009). Examining the codes together allowed the researcher to then narrow the codes to succinctly represent the data. These narrower codes were placed in another column next to the lengthy code list (Saldana, 2009).

Once the data collected from the student teaching experience had been coded the information was compared to the data from the methods course study. Data from the methods course had been examined in the same way as during the student teaching. Therefore, the code lists for the participants were pulled from the methods course data. The coding for the methods course was also in a similar table for tools, processes, pedagogical approaches, and the learning cycle. Codes for tools during methods class and tools for student teaching were read through to determine similarities, differences, or changes. This continued for processes, pedagogical approach, and learning cycle codes. The researcher tried to determine what changes, if any, occurred from mathematics-science methods class to student teaching in understanding and development of approaches in mathematics. The codes were examined in chronological order to determine shifts or changes in practice. Systematic searches were made to find corroborating or contradictory evidence. Generalizations were then made within each case across the different periods of data collection. Finally the two cases were compared.

After reviewing the data sets using grounded theory (Charmaz, 2006; Glaser & Strauss, 1967), a number of themes emerged. The remaining sections of this paper present an analysis and interpretation of Jane and Kate's development of approaches to mathematics in student teaching that first emerged in the methods courses.

Jane and Kate: Methods Class

Jane and Kate had varying conceptions in their methods course of tools for conceptual development, processes for meaningful learning, and pedagogical approaches. These conceptions changed somewhat from when they initially entered the methods course to when they completed it. Table 5 and Table 6 provide a summary of those areas for each case. Initially, Jane conceived of teaching both in a way that would allow students to "see" and "do". In contrast, Kate conceived of hands-on teaching in mathematics for real-life concepts such as time and money. Jane focused more on the engage and explore phases since this helped students to "see" and "do" the mathematics. Kate focused on the engage phase as a means of connecting with students' prior knowledge. At the end of the methods course it appeared as if the learning cycle approach, particularly the explore and engagement aspects, had affirmed Jane's ideas of how mathematics should be taught. It also seemed as if Kate embraced the learning cycle as means for students to engage and explore concepts but under teacher direction. Observing them during their student teaching provided information to see if they had maintained or altered their conceptions of teaching mathematics using tools, processes, and the learning cycle approach.

Table 5
Jane-Methods Class

	Initial Conceptions	End Conceptions
Tools	Hands-on; "See" concepts	Students to conduct experiments; Learn for themselves
Processes	Reasoning	Peer discussion and questioning techniques to foster reasoning
Pedagogical approaches	Experiments; Games and activities	Inquiry-based for both subjects
Approach to teaching science and mathematics	2 different approaches Science as experiments-mathematics as games and manipulatives	LC and tools for concept development for both subjects. Notebooks for science-games and activities for mathematics

Table 6
Kate-Methods Class

	Initial Conceptions	End Conceptions
Tools	In science-to enhance concepts in science book In mathematics- tools for real life (i.e. time and money)	Teacher controlled use of tools for both subjects
Processes	Teacher directed experiences	Limited processes (reasoning, connections, multiple representations) due to need to control the lesson
Pedagogical approaches	Teacher explains-student see examples	Hands-on in science for reward or treat Hands-on in mathematics for real life (i.e. money, time)
Approach to teaching science and mathematics	2 different approaches Science use hands-on mathematics use real life experiences	Learning cycle and inquiry in both Science use hands-on Mathematics use everyday concrete objects

Results

Jane: Student Teaching

At the beginning of her two weeks of teaching, Jane was overwhelmed with the responsibilities of designing, planning, and implementing every subject. The first observed mathematics lesson was poorly designed and implemented. Initially her approach to teaching mathematics was very inefficient. Her first lesson focused on tools in a procedural way. Students measured two items in a fifty minute time span. Her struggle with discipline along with poor lesson planning interfered with her teaching of the lesson. She seemed to take a step backwards from the way she conceptualized tools in the methods class. In methods class she conceptualized tools as a way for students to learn abstract concepts through concrete experiences. Her mathematics teaching in the internship may have been patterned after the way her cooperating teacher taught mathematics or she may have fallen back on the way she experienced mathematics.

The second lesson also focused on measurement. She demonstrated how to measure and distributed buckets. The buckets had materials for the students to measure items to the nearest ¼ inch, ½ inch, and inch. Tools were once again used for procedures. After observing the second lesson it was clear that Jane was making up her own mathematics lessons. They were clearly missing the components of a quality lesson. These missing components led to of-task behavior. This second lesson was just as poorly done as the first lesson: “It is torture for me to sit and watch such off-task behavior. The lack of management is interfering with the mathematics and the poorly designed lesson is encouraging additional discipline problems” (Researcher journal, 4/15).

When asked what specific teaching practices she wanted to improve she said, "Having the materials prepared and ready. Making sure they know the difference between ¼ and ½. Making sure they weren't fighting." (J, FI, 4/15). The areas she mentioned she wanted to improve were not in her lesson the day before. Although she was trying to improve her practice, she clearly needed more guidance in thinking through all parts of a lesson: how would the concept be presented? How would students be engaged? How would students be accountable for their learning? After the second lesson observation those were the types of questions I asked her to think about in the next mathematics lesson she would be teaching. I told her that until she became a strong experienced teacher that she needed to use research-based curriculum and think of the elements of the learning cycle in her lesson development. We discussed resources she had that she could use to teach a successful mathematics lesson.

Her teaching style was often very teacher directed at the beginning of class. Then she would have students complete a task to explore or extend the concept further. Throughout her teaching she used questioning as a means for students to reason about the concept she was teaching. She did this in her field placement teaching during her methods class as well. She wanted students to understand for themselves and be able to explain their reasoning. She would often follow with, "How did you know?" When asked in the follow-up interview "What role did the learning cycle play in your lesson development and implementation? She responded, "Engage part. I wanted to get them going. Evaluate. I wanted to see how they did." (J, FI, 4/14). She did try to engage her students, but they were not actively involved in any new learning. Furthermore, her ideas about the aspects of the learning cycle were very limited. Engagement in the learning cycle means students are focused on a problem or event. She interpreted engagement as the students participating in the assigned task, which was not a problem or event in the aspect of inquiry-based teaching. She similarly focused on the engagement and explore phases of the learning cycle during methods class. In her blogs in methods class she often referred to the exploration aspect of her lessons. She did use questioning techniques to have students think about concepts. “Stack your books in the middle of the table. What did you figure out about the books? What is something you concluded? What is something you noticed?” (J, O, 4/14).

The third lesson showed dramatic improvement from the first lesson, and seemed to be the turning point for Jane. In the third lesson she had the students vote on their favorite sports team and pet when they arrived at school. During the mathematics lesson she had them tally the information and relate different ways the information could be displayed. She used the NCTM website, Illuminations, to illustrate how graphs look different based on the information they represent. She then led them back to the data they collected earlier that morning. Based on the data, she had them describe what a graph of the data would look like. She gave them tiles to make a graph on their desk. In the lesson she used a variety of tools to connect different representations of data. She used drawings, the interactive website, the students, and tiles to help them “see” the mathematics. Her questions demonstrated she wanted students to reason and make connections with the representations. This was a similar pattern for her teaching in methods class. She used visual representations and questions to help students understand. When asked about the role of the learning cycle in the lesson Jane responded,

> Explore-Thinking about the other day. Thinking about the 5E’s. Engage-Asking questions who remembered about bar graphs. Explore-Using the computer to see how it looks. Elaboration-working with the tiles. Sketching it out. How they were doing it on

> their own. Evaluation-Watching them fill in the graph. Used the Handful lesson from Investigations. (J, FI, 4/16)

The behavior management issues were noticeably less in the third observation as well. The students were engaged, she moved the lesson along at a good pace, and she connected the data to the students' interests.

By the end of the two weeks teaching she attempted to develop well thought out lessons. During the times that she was observed teaching mathematics, her skills in selecting tools and management of the tools improved. Moreover, by the end of the two weeks she was using a variety of tools within a lesson to model concepts for students as well as tools for students to use themselves to understand concepts. For example, she used fraction magnets on the board, animal pieces on the document camera, and the students had their own fraction circle sets to understand fractional parts. She thought of more than just the engage phase. When she began to develop lessons, thinking about all phases of the learning cycle, they were more successful. In the data lesson she intentionally thought about what students would be doing for each phase of the learning cycle. However, she interpreted the learning cycle as a set of steps to follow rather than thinking about it as a cyclical learning process. With additional coaching, she may have developed a stronger understanding of teaching math with the learning cycle.

Because students were engaged and on-task, the quality of the lessons the second week was much better than the quality of the lessons the first week:

> I am amazed at Jane's teaching today. By no means was it a perfect lesson. She still had a couple of behavior issues to deal with, but wow was it different from the first two lessons I observed. We talked after the last observation about different fractional representations to help students understand fractional concepts. She did make the fraction circles so the

> students could each have their own sets. She needed to move the lesson along a little bit faster. Students were getting bored. But all-in-all the quality of the lesson was so much better. (Research journal, 4/23)

During the first week when she seemed to be floundering she fell back on a more traditional approach to mathematics. During the second week when she planned better lessons and used standards based resources from National Council of Teachers of Mathematics and the Investigations (Person Education, 2007) series her approach was more hands-on in nature. Her approach the second week influenced the way she used tools as well. Her use of tools the second week was for concept exploration and understanding not just for procedures. In her final reflection she noted,

> I taught a fraction review lesson with fraction circles. These were the concrete tools I used for each student. I engaged them by showing them a program on Illuminations site with the fraction circle. I asked them what they thought the circle would look like with certain fractions. I then had them explore with the fractional pieces that were in the bags to see what fractional parts they had. I had them apply what they knew about fractions to find equivalents with their pieces (J, FR).

She also spent less time focusing on discipline the second week because of all of the combined factors: well thought out lesson plans, student engagement, and student involvement throughout the lesson.

Jane appeared to take a step backwards initially in mathematics teaching from where she ended in methods class. With some coaching, she was able to develop better lessons, although not true inquiry-embedded lessons. Her use of tools shifted from tools for procedures to tools for reasoning. She maintained throughout methods and student teaching the practice students explaining how they understand. From the first day of methods class she indicated that she wanted students to be able to “see” the mathematics. With coaching, she was able to develop lessons that fit her need for students to “see”. Her approach maintained a traditional approach in which the teacher demonstrates, students complete practice, and the teacher reviews. The practice element for the students often involved hands-on materials.

Kate: Student Teaching

Kate’s first observed lesson was also procedure focused and did not involve inquiry within the learning cycle. In the first lesson Kate directed students as they played various games to promote speed of multiplication facts. She kept students on task throughout the various fact games they played. She summarized the lesson by reminding students of tricks or devices to help them remember certain ones. “Remember 5,6,7,8? [writes on the board 56=7x8] Who remembers the 9 trick? [Shows the 9’s with fingers]” (K, O, 4/20). Although the students were well managed, I was concerned about the quality of task she had designed for her teaching time.

> I just observed a lesson in which students practiced multiplication facts for 45 minutes. Students are not involved in any new learning. This is for speed of facts. That does have its place but within a context. I know she had the freedom to design this lesson. I am concerned that she resorted to this type of lesson because it is comfortable for her to implement (Researcher journal, 4/20).

I did not see where the students were thinking about mathematics in deep and meaningful ways. Processes in her initial mathematics lesson were for facts. I asked her in the follow-up interview what the goal of the lesson was and she said, “for students to get back into the swing of things” (K, FI, 4/20). After the multiplication fact lesson we discussed what she had planned for the week. She said she was going to move to division. I asked her how she was going to teach this. She said she was just going to show them how. I asked her if she thought about using an Investigation (Pearson, Education, 2007) to teach division. I asked her to think on her mathematics methods classes and ways to make lessons more meaningful for students. We discussed representations that would help students see the relationship between multiplication and division. She said she would look into the tower investigation for the next lesson. The tower lessons involve students working in pairs to record multiples of a given number on a strip of calculator tape. The tower is then used over several days as students complete tasks and explore the relationships of the numbers in the tower.

For the second observation I observed her teaching the multiple towers lesson. In that lesson students were relating multiplication and division, finding patterns, and reasoning about numbers. The nature of the number tower lesson focused the students towards reasoning and communication of ideas. Kate modeled how to record the number tower:

> I am already at my hip. What number do you think I will be at my shoulder? Let's make some predictions [writes on board as student call out]. Who has a prediction of what my number is going to be when I get to the top? Who is noticing some patterns as we go up?" (K, O, 4/21).

I could tell Kate was nervous as she taught the lesson. She stammered and often referred to the teacher guide in following the lesson. Her students answered questions about the example tower and then made their tower with their partner. At the end of the lesson we discussed how the lesson went. She told me she thought it went "pretty good for teaching it for the first time" (K,FI, 4/21).

Her second mathematics lesson in comparison to her first was of much greater quality. Students used towers as tools to bridge the concepts of multiplication and division. Students used processes that focused on concept building. The mathematics lessons that followed used research based lessons and the use of tools were for different purposes. Students were using number towers, calculators, and problems to understand division concepts. In mathematics she changed her pedagogical approach from a fact based teacher directed one to a more hands-on student exploring approach but with a great amount of teacher direction.

On the third day she continued with the tower lesson. She had students complete a number walk around the room. The students had to find the 10th, 15th, and 20th numbers in the towers. They also had to record patterns they noticed in a tower. In her mathematics methods class she taught a lesson in which students had to figure out a pattern. She ended up giving students the pattern instead of giving them time to figure it out. Her number tower lessons were very similar. If students didn't figure something out, she would tell them. She did use the tower as a tool to develop multiplication and division, but she interfered in students figuring the math out on their own. Her focus on processes was for students to find the answers as to which numbers were the 10th, 15th, and 20th. She did not recognize the lesson in the larger scope of multiplication and division. She did think about the learning cycle in her lesson development, "They were engaged in the beginning. They had to find a pattern. Pretty much it was explore the whole time with pairs discussing" (K, FI, 4/22).

In her methods class, she often referred to the engage and explore portions of the learning cycle. She liked the engage part because she felt like it helped get students interested in the lesson. She thought the explore portion was most important because "students really construct their own knowledge" (K, Week 7 Methods). With the number towers students were given plenty of time to explore the different towers. However, she did not expand the number towers to the depths of multiplication and division it is intended to develop.

At the end of the week, she reverted back to her original plans and had students completing procedural review problems. Students who finished early were given problems to solve with the towers. Kate did not go over those answers or discuss strategies students used to solve the tower problems. Instead she focused on the answers to the procedure review problems. Lack of teaching experience or a lack of confidence in continuing the use of the investigation lessons may have been contributing factors. Yet, in the follow-up discussion when asked about the learning cycle in the lesson she replied, "Explore-I feel they had to look at the division problems and look hard and ask, "What tools do I have? How can I figure it out based on what tools I know?" (K, O, 4/23). Although some students may have explored solving multiplication and division problems with the towers, she left out the evaluation phase in this process. She did not find out how students solved the problems or how they used the tools in the process.

Kate had several interferences in her teaching. Her mathematics lessons that she designed originally were based on sources that were not research based. When her lessons were focused on procedures, the tools and processes were also for answers. When she followed the investigation type lessons, students had more time to explore concepts and tools were used as the key part of the lesson. She did expand the lessons into multiplication and division but not to the intended depths of the lesson. She did not fully trust the reform-based lessons. She placed her confidence in the lessons she created. The lessons she created were very low-level in thinking, focused on procedures, and reverted back to a traditional approach to teaching mathematics. The learning cycle was not an approach she used in her lessons. In our discussions after her lessons when asked about the learning cycle, she would weakly try to relate the lesson to aspects of the learning cycle" "Engage-The students played a game last week and worked problems. The kids were not where we wanted them to be [with their multiplication facts]" (K, FI, 4-20). In methods class she was able to successfully plan and implement mathematics lessons using the learning cycle approach. In one of her blogs she responded, “I have always thought of the learning cycle as a useful tool for teachers to go by when planning their lessons” (K, Week 6). However, she may have believed the learning cycle useful in planning but she didn’t put that into her own practice. Similar to Jane, Kate held naïve views of the learning cycle as an approach to teaching.

Discussion

The cases of Jane and Kate present two beginning teachers in their development process. Kate appeared to be a somewhat stronger student in methods class than Jane. They both presented the idea of using the learning cycle in their mathematics teaching at the end of the methods course. Following them through internship was quite revealing. An outsider may have perceived Kate as a stronger intern due to the well behaved students in the class. Upon closer examination however, the teacher-directed style and low-level questioning revealed other aspects of her teaching that needed improvement. Looking back at her data from the methods class revealed her beliefs about teaching mathematics and science in limited ways and under controlled conditions. Richards, Levin, and Hammer (2011) posited that student teachers weren’t able to maintain reform based practices because they did not alter their belief systems during the preparation program or they have teaching qualities that make it difficult for them to support that teaching approach. Her actions may be attributed to her deeply held beliefs about the teaching and learning of mathematics. Jane, from the outside, may have been perceived as a weaker teacher due to her struggles in classroom management. However, Jane was quite tenacious in improving her practice and having students learn in meaningful ways. Examining her pre-test from the first day of class reveals her concern that student be able to “see” the mathematics for themselves.

It appeared at the end of methods class that both Jane and Kate had embraced aspects of the learning cycle in their mathematics teaching. The responses on the post-test could have been due to inundation with the learning cycle approach throughout the summer semester. They had a semester in-between mathematics methods and student teaching in which the learning cycle was not the focus. It became apparent after observing and talking with them in student teaching, that they maintained their deeply held beliefs about teaching mathematics from methods class through internship. They both seemed to try to fit aspects of the learning cycle approach within their belief systems. Jane wanted hands-on to help students "see" the concepts and became attached to the engage and explore phases and a means of helping students "see" the concepts. Kate wanted mathematics to focus on real-life mathematics. She liked the engagement aspect of the learning cycle because it helped put students on track for the lesson that she would direct the rest of the way. She believed other aspects of the learning cycle should be conducted through teacher guidance and control.

During methods class they both completed required teaching assignments using the learning cycle. However, during their two weeks of full-time teaching they designed the lessons based in their level of comfort in how to teach mathematics. Initially both started out with very traditional types of lessons. It both seemed as if they had taken a step backwards from the teaching they exhibited in methods class. This is interesting because in methods class they wanted students to see or connect with real-world mathematics but this was not evident based on the first lesson observation. When they were responsible for designing, planning, and implementing multiple subjects they both reverted to a traditional style of teaching.

A noted similarity for both Jane and Kate was that they designed lessons for their two week lesson plans from "other" sources. For the case of Jane, since she did not have strong classroom management skills, the poor lessons caused additional off-task behavior. Novice teachers are not curriculum designers or developers. They have not developed the expertise for their subject, grade, or needs of the students to be expected to invent their own curriculum. In the methods class, all of the material that was used had been tested in classrooms and was research-based. The lessons were easy for them to use and promoted conceptual development of mathematics. The student teachers did not turn to these materials for their two-weeks of full-time teaching. The sources for their lessons were off of the top of their head or worksheets they found in various places. These "other" sources resulted in poorly designed lessons in which students were not being challenged to learn new materials in meaningful ways.

In both cases after discussing the mathematics lesson, both preservice teachers changed their original lessons to investigation type lessons. The researcher supported the student teachers to alter their lessons to include investigative type lessons. Although Kate did use some of the *Investigations* (Pearson Education, 2007) in her mathematics lessons, she did not follow them the way they were intended. She taught them in a teacher controlled manner that did not allow the students to fully explore the mathematics. The fact that Kate was willing to teach investigative lessons that she was unfamiliar with gives hope for Kate's future mathematics teaching. Jane's teaching improved with coaching and guidance, and she seemed to find more of her comfort zone once she started using NCTM materials and *Investigations* (Pearson Education, 2007). This fulfilled her desire for students to be able to "see" the mathematics. She was always careful to pose questions that would make the students think. Yet, Jane also maintained a mathematics approach in which the teacher explains, student completes a task, and the teacher summarizes.

In both cases the learning cycle and inquiry initially seemed to be a forgotten approach to teaching mathematics. A lack of connection often exists between the experiences of the methods course and actual teaching (Manouchehri, 1999). The learning cycle was not used by the cooperating teachers and therefore not enforced as an approach with the student teachers. Putman (2009) likewise noted that student teachers shifted towards the practices of their cooperating teachers. Hargreaves (1984) also noticed new teachers copying the style of the veteran teachers. Jane and Kate were not in classrooms in which the learning cycle was used as a framework for inquiry embedded teaching, despite the fact that the teachers had participated in ongoing mathematics professional development using reform curricula and science professional development based on learning cycles. Leonard, Boakes, and Moore (2009) also concluded that appropriate learning environments were necessary to maintaining inquiry-based practices.

Implications

The nature of the dual science and mathematics methods course provided a unique methods course experience. The purpose of that common approach to the methods class was to help preservice teachers see that the learning cycle as an inquiry-embedded approach for science also applied to mathematics. For Jane, it appeared as if the methods course affirmed her need for students to experience mathematics. Kate began methods course with a very naïve view of mathematics as real-world applications. She appeared to have made changes in her thinking about how to approach the teaching of mathematics. Kate successfully taught lessons using the learning cycle for mathematics during methods class. She was thought by the researcher to be a strong mathematics teacher. She talked about the importance of students' discovering concepts on their own, the use on concrete experiences to develop understanding, and the importance of the learning cycle and inquiry. The researcher expected Kate to be a strong mathematics teacher in student teaching. Perhaps in the case of Kate, it really demonstrated that she is a strong student. She followed the directions and assignments required for the methods class, including writing a strong blog. Without the structure of the learning cycle imposed on her mathematics teaching, she designed lessons that were very low-level in nature and represented her comfort level in teaching.

Although both Jane and Kate initially taught mathematics lessons that were very shallow they did alter their lesson plans to include investigative type lessons. Through discussion about the lesson and methods class, both implemented changes in their mathematics lessons. The researcher’s direct involvement with Jane and Kate impacted their decisions on their mathematics teaching. Their pedagogy was not one of true inquiry within the learning cycle. However, it progressed to using tools for meaning and sense-making, processes for reasoning and communications, and lessons that were more hands-on in nature for the students.

The researcher served as a coach to help Jane and Kate improve their practice. Teaching inquiry-based lessons can be a challenging and daunting task for novice teachers. Although the learning cycle provides a framework for inquiry, beginning teachers need help in using it for mathematics. Perhaps teacher preparation institutions and school partners should think about establishing coaches within student teaching to provide additional support for student teachers. This research indicates the roles of supervisors and other support personnel can help influence and remind new teachers about reform-based teaching practices. Having the preservice teachers put reform-based approaches in practice not only helps to build their confidence but also their abilities to teach reform-based lessons. Teaching reform-based practices takes more thought and complexity of teaching. Mathematics coaches can help student teachers in their development and implementation of reform-based lessons. Practice teaching using reform-based curricula can provide the teaching practice, build pedagogical repertoire, and serve as a foundation for future teaching.

Additionally, both Jane and Kate needed more direct advice on planning and teaching inquiry-based mathematics lessons. They both reverted to a traditional style of mathematics teaching when it came time for them to design their full time teaching. Imposing parameters for preservice teachers similar to those of the methods course, including using reform-based curriculum and more developed lesson plans, may provide additional scaffolding as preservice teachers develop their craft. Imposing similar parameters assumes the cooperating teacher is of like mind. Therefore, teacher preparation institutions need to continue to develop relationships with school partners to help establish those similar parameters.

Developing school partnerships that helped in-service and preservice teachers foster a practice of inquiry-embedded practices within the learning cycle would be an ideal situation. Although preservice teachers were expected to use the learning cycle approach in their laboratory teaching experiences during their methods courses, this did not carry over into their internship. The observation-conferencing technique made a difference in the mathematics teaching of both student teachers. The quality of the lessons improved due to the focus of tools for conceptual understanding, use of processes for reasoning, and the learning cycle approach. Placing mathematics coaches with student teachers would provide a continuum of training to help student teachers develop meaningful lessons using "tools of inquiry" and designed instruction to develop students problem solving and thinking skills (INTASC, n.d.).

References

Akerson, V. L. (2005). How do elementary teachers compensate for incomplete science content knowledge? *Research in Science Education, 35*(2-3), 245-268. Retrieved from http://www.eric.ed.gov

Alsup, J. K. (2003). New classroom rules to promote preservice elementary teachers' mathematics learning. *Education, 123*(3), 609-615. Retrieved from http://search. ebscohost.com

Atkin, J. M., & Karplus, R. (1962). Rebuilding the science program. *The Science Teacher, 29*(5), 45-51.

Atkinson, R. D., & Mayo, M. (2010). *Refueling the U.S. innovation economy: Fresh approaches to science, technology, engineering, and mathematics (STEM) education*. Washington, D.C.: Information Technology and Innovation Foundation. Retrieved from ERIC database. (ED521735)

Bales, B. L., & Mueller, J. J. (2008). Preparing teachers for a new era: Building bridges in the learning-to-teach professional sequence. *The New Educator, 4*(2), 152-168. Retrieved from http://seacrh.ebscohost.com

Ball, D. L. (1988). *Research on teaching mathematics making subject matter knowledge part of the equation*. Retrieved from ERIC database. (ED301467)

Beeth, M. E., & McNeal, B. (1999). *Co-teaching mathematics and science methods course*. Retrieved from ERIC database. (ED443666)

Bleicher, R.E. (2006). Nurturing confidence in preservice elementary science teachers. *Journal of Science Teacher Education*, *17*(6), 165-187.

Bogdan, R. C., & Biklen, S. K. (1982). *Qualitative research for education: An introduction to theory and methods*. Boston, MA: Allyn & Bacon

Bolton, C. (1997, February). *Developing teachers: A novice-expert study of initial teacher preparation.* Paper presented at the 49th Meeting of the American Association of Colleges for Teacher Education, Phoenix, AZ. Retrieved from ERIC database. (ED405335)

Bybee, R.W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Castro, A. (2006). Preparing elementary preservice teachers to use mathematics curriculum materials. *Mathematics Educator*, *16*(2), 14-24. Retrieved from http://search.ebscohost .com

Charmaz, K. (2005). Grounded theory in the 21st Century: Applications for advancing social justice studies. In N. K. Denzin, & Y. S. Lincoln (Eds.), *The Sage handbook of qualitative research* (3rd ed.). (pp. 507-535). Thousand Oaks, CA: Sage Publications.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. Thousand Oaks, CA: Sage Publications

Chick, H. L. (2007). Teaching and learning by example. In J. Watson & K. Beswick (Eds.) *Mathematics: Essential Research, Essential Practice. Volumes 1 and 2. Proceedings of the 30th Annual Conference of the Mathematics Education Research Group of Australasia, Adelaide, SA* (pp. 3-21). Mathematics Education Research Group of Australasia. Retrieved from http://www.eric.ed/gov

Clark, J. (2005). Achieving teacher education standards through a mathematics performance-based assessment: A case study of five Colorado preservice teachers on field experience.

International Education Journal, *5*(5), 55-70. Retrieved from http://search.ebscohost. com

Conference Board of the Mathematical Sciences [CBMS]. (2001). *The mathematical education of teachers* (Vol. 11). Providence, Rhode Island: American Mathematical Society.

Connelly, F. M., & Clandinin, D. J. (1986). On narrative method, biography and narrative unites in the study of teaching. Retrieved from ERIC database. (ED277664)

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, *44*(4), 613-642. Retrieved from http://search. ebscohost.com

Cuenca, A. (2011). The role of legitimacy in student teaching: Learning to "feel" like a teacher. *Teacher Education Quarterly*, *38*(2), 117-130. Retrieved from http://search.ebscohost. Com

Davis, E., & Petish, D. (2005). Real-world applications and instructional representations among prospective elementary science teachers. *Journal of Science Teacher Education*, *16*(4), 263-286. doi:10.1007/s10972-005-8892-4

Emenaker, C. (1996). A problem-solving based mathematics course and elementary teachers' beliefs. *School Science and Mathematics*, *96*(2), 75-84.

Even, R., Tirosh, D., & Markovits, Z. (1996, July). *Teacher subject matter knowledge and pedagogical content knowledge: Research and development.* Paper presented at the International Group for the Psychology of Mathematics Education, Valencia, Spain (pp. 150-165). Retrieved from http://www.eric.ed.gov

Feiman-Nemser, S., & Buchmann, M. (1986). *Knowing, thinking and doing in learning to teach: A research framework and some initial results. Research Series No. 180*. Retrieved from ERIC database. (ED274653)

Fennell, H. A. (1993). *Student teachers' evaluation of their preparation for internship course: A case study.* Retrieved from ERIC database. (ED361335)

Fuller, R. A. (1996, October). *Elementary teachers' pedagogical content knowledge of mathematics*. Paper presented at the Mid-Western Educational Research Association Conference, Chicago, Il. Retrieved from ERIC database. (ED401270)

Gee, C. J., Boberg, W. S., & Gabel, D. L. (1996, April). *Preservice elementary teachers: Their science content knowledge, pedagogical knowledge, and pedagogical content knowledge*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, St. Louis, MO. Retrieved from ERIC database. (ED393702)

Glaser. B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Piscataway, NJ: Aldine Transaction.

Goodnough, K., & Nolan, B. (2008). Engaging elementary teachers' pedagogical content knowledge: Adopting problem-based learning in the context of science teaching and learning. *Canadian Journal of Science, Mathematics & Technology Education*, *8*(3), 197-216. doi:10.1080/14926150802315130

Gresham, G. (2007). A study of mathematics anxiety in pre-service teachers. *Early Childhood Education Journal*, *35*(2), 181-188. doi:10.1007/s10643-007-0174-7

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. W. (2009). Teaching practice-A cross-professional prospective. *Teachers College Record*, 111(9), 2055-2100. Retrieved from http://search.ebscohost.com

Hargreaves, A. (1984). Experience counts, theory doesn't: How teachers talk about their work. *Sociology of Education*, *57*(4), 244-254. Retrieved from http://search.ebscohost.com

Hatch, J. A. (2002). *Doing qualitative research in education settings*. Albany, NY: State University of New York Press.

Heywood, D. S. (2007). Problematizing science subject matter knowledge as a legitimate enterprise in primary teacher education. *Cambridge Journal of Education, 37*(4), 519-542. doi:10.1080/03057640701705856

Hill, L. (1997). Just tell us the rule: learning to teach elementary mathematics. *Journal of Teacher Education*. *48*(3), 211-222. Retrieved from http://search.ebscohost.com

Hoffer, A. R. (1993). The excitement of learning with our students: An escalator of mathematical knowledge. *The Mathematics Teacher*, *86*(4), 315-319.

Interstate Teacher Assessment and Support Consortium [INTASC] (n.d.). *The INTASC standards*. Retrieved from http://www.wresa.org/Pbl/ The%20INTASC% 20 Standards%20overheads.htm

Jaeger, M., & Lauritzen, C. (1992, November). *The construction of meaning from experience*. Paper presented at the Annual Meeting of the National Council of Teachers of English, Louisville, KY. Retrieved from ERIC database. (ED358410)

Johnson, W. N. (1980). *Perception changes of students studied in a field-centered methods course for teachers of elementary school mathematics and upon completion of student teaching: A follow-up study*. Retrieved from ERIC database. (ED187545)

Jong, O. D. & Brinkman, F. (1999). Investigating student teachers' conceptions of how to teach: International network studies from science and mathematics education. *European Journal of Teacher Education*, *22*(1), 5-9. Retrieved from http://search.ebscohost.com

Jurdak, M., & Shahin, I. (2001). Problem solving activity in the workplace and the school: The case of constructing solids. *Educational Studies in Mathematics*, *47*(3), 297-315. Retrieved from http://www.search.ebscohost.com

Justi, R., & Gilbert, J. (2000). History and philosophy of science through models: Some challenges in the case of the 'atom'. *International Journal of Science Education*, *22*(9), 993-1009. Retrieved from http://search.ebscohost.com

Justi, R., & van Driel, J. (2005). The development of science teachers' knowledge on models and modeling: promoting, characterizing, and understanding the process. *International Journal of Science Education*, *27*(5), 549-573. Retrieved from http://search .ebscohost.com

Kelly, J. (2000). Rethinking the elementary science methods course: A case for content, pedagogy, and informal science education. *International Journal of Science Education, 22*(7), 755-777. Retrieved from http://search.ebscohost.com

Kind, K. K. (1999). *Dialogue on early childhood science, mathematics, and technology education: First experiences in science, mathematics, and technology*. Retrieved from http://www.project2061.org/publications/earlychild/online/experience/ lind.htm

Lancy, D. F. (1993). *Qualitative research in education: An introduction to the major traditions*. White Plains, NY: Longman Publishing Group.

Leonard, J., Boakes, N., & Moore, C. M. (2009). Conducting Science Inquiry in Primary Classrooms: Case Studies of Two Preservice Teachers' Inquiry-Based Practices. *Journal of Elementary Science Education*, *21*(1), 27-50. Retrieved from http://search.ebscohost. com

Lever-Duffy, J., & MacDonald, J. B. (2010). *Teaching and learning with technology* (4th ed). Upper Saddle River, N.J.: Pearson.

Lonning, R. A., & DeFranco, T. C. (1994). Development and integration of an integrated mathematics/science preservice elementary methods course. *School Science and Mathematics, 94*(1), 18-25.

Lubinski, C. A., Otto, A. D., Rich, B. S., & Jaberg, P. A. (1995, October). *Content knowledge, beliefs, and practices: A comparison among six preservice teachers*. Paper presented at the Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education, Columbus, OH. Retrieved from ERIC database. (ED389600)

Manouchehri, A. (1997). School mathematics reform: Implications for mathematics teacher preparation. *Journal of Teacher Education*, *48*(3), 197-210. Retrieved from http://search.ebscohost.com

Marek, E. A. (2008). Why the learning cycle? *Journal of Elementary Science Education, 20*(3), 63-69.Retrieved from http://search.ebscohost.com

Marek, E. A., & Cavallo, A. M. (1997). *The learning cycle: Elementary school science and beyond.* Portsmouth, NH: Heinemann.

Marek, E. A., Maier, S. J., & McCann, F. (2008). Assessing understanding of the learning cycle: The ULC. *Journal of Science Teacher Education*, *19*(4), 375-389. Retrieved from http://search.ebscohost.com

Marshall, C., & Rossman, G. B. (1995). *Designing qualitative research* (2nd ed.). Thousand Oaks, CA: Sage Publications.

McGinnis, J., & Parker, C. (1999, March). *Teacher candidates' attitudes and beliefs of subject matter and pedagogy measured throughout their reform-based mathematics and science teacher preparation program*. Paper presented at the Annual Meeting of the National Association of Research in Science Teaching, Boston, MA. Retrieved from ERIC database. (ED 429830)

McLeod, K., & Huinker, D. (2007). University of Wisconsin-Milwaukee mathematics focus courses: Mathematics content for elementary and middle grades teachers. *International Journal of Mathematical Education in Science Teaching*, *38*(7), 949-962. doi:10.1080/00207390701579498

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco, CA: Wiley & Sons.

Molina, D., Hull, S., Schielack, J., & Education, T. (1997). *Guidelines for the Mathematical Preparation of Prospective Elementary Teachers*. Retrieved from ERIC database. (ED 436370)

Morrison, J. (2008). Individual inquiry investigation in an elementary science methods course. *Journal of Science Teacher Education*, *19*(2), 117-134.

National Council of Teachers of Mathematics [NCTM]. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

National Research Council [NRC]. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Science Board [NSB] (2004, January). *An emerging and critical problem of the science and engineering labor force: A companion to Science and Engineering Indicators 2004*. Retrieved from http://www.nsf.gov/statistics/nsb0407/

Neal., L. A. (1962). Method of scientific literacy. *The Science Teacher*, *29*(5), 53-55.

Noori, K. K. (1994). *A constructivist/reflective paradigm: A model for the early childhood program at Tuskegee University*. Retrieved from ERIC database. (ED370888)

Pearson Education (2007). *Investigations in number, data, and space*. Glenview, Ill: Scott Foresman.

Philippou, G., Charalambos, C., & Leonidas, K. (2003). The development of student teachers' efficacy beliefs in mathematics during practicum. In *Proceedings of the 27th International Group for the Psychology of Mathematics Education Conference Held Jointly with the 25th PME-NA Conference (Honolulu, HI). Vol.*, p.7 -14. N. International Group for the Psychology of Mathematics Education. Retrieved from http://search.ebscohost.com

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Putman, S. M. (2009). Grappling with classroom management: The orientations of preservice teachers and impact of student teaching. *The Teacher Educator*, *44*(4), 232-247. Retrieved from http://search.ebscohost.com

Quinn, R. J. (1997). Effects of mathematics methods courses on the mathematical attitudes and content knowledge of preservice teachers. *The Journal of Educational Research*, *91*(2), 108. Retrieved from http://search.ebscohost.com

Renner, J. W., & Lawson, A. E. (1973). Piagetian theory and instruction in physics. *The Physics Teacher*, *11*(3), 165-169.

Richards, J., Levin, D. M., & Hammer, D. (2011, April). *Supporting preservice teachers' reform based practices: The importance of intellectual and emotional support in a community*. Paper presented at the Annual Meeting of American Educational Research Association, New Orleans, LA. Retrieved from ERIC database. (ED520061)

Saldana, J. (2009). *The coding manual for qualitative researchers*. Thousand Oaks, CA: Sage Publications.

Sambs, H. (1991, April). *Problem solving in physics and mathematics-What do they have in common? (Creating a base for research and teaching).* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Geneva, WI. Retrieved from ERIC database. (ED335222)

Shapiro, S. (1983). Mathematics and reality. *Philosophy of Science, 50*(4), 523-548. Retrieved from EDS Foundation Index.

Spielman, L. J., & Lloyd, G. M. (2004). The impact of enacted mathematics curriculum models on prospective elementary teachers' course perceptions and beliefs. *School Science and Mathematics*, *104*(1), 32-44.

Sriraman, B., & Lesh, R. (2007). A conversation with Zoltan P. Dienes. *Mathematical Thinking and Learning*, *9*(1), 59-75.

Stake, R. E. (2005). Qualitative case studies. In N.K. Denzin & Y. S. Lincoln (Eds.), *The Sage Handbook of Qualitative Research* (3rd ed.). (pp. 433-466). Thousand Oaks, CA: Sage Publications.

Steen, L. A. (1990). *Science and mathematics education: Similarities and differences*. Retrieved from http://www.stolaf.edu/people/steen/Papers/similarities.html

Stuessy, C. L. (1993). Concept to application: Development of an integrated mathematics/science methods course for preservice elementary teachers. *School Science and Mathematics, 93*(2), 55-62.

Swartz, R. (1982). Alternative learning strategies as part of the educational process. *Science Education, 66*(2), 269-279.

Taylor, C. (2009). *The effects of a combined mathematics content/methods course involving Learning Cycles on preservice elementary teachers' beliefs about the nature, teaching and learning of mathematics. Ed.D. dissertation, Temple University, United States-Pennsylvania.* Retrieved from Dissertations & Thesis: A&I. (Publication No. AAT 3344406).

Tracy, D. M. (1999). SSMiles. *School Science and Mathematics*, *99*(7), 400-408.

Tracy, D. M. (2003). Linking math, science, and inquiry-based learning: An example from a mini-unit on volume. *School Science and Mathematics*, *103*(4), 400-413.

van Es, E. A., & Conroy, J. (2009). Using the Performance Assessment for California Teachers to Examine Pre-Service Teachers' Conceptions of Teaching Mathematics for Understanding. *Issues in Teacher Education*, *18*(1), 83-102. Retrieved from http://www.eric.ed.gov

Weld, J., & Funk, L. (2005). "I'm not the science type": Effect of an inquiry biology content course on preservice elementary teachers' intentions about teaching science. *Journal of Science Teacher Education*, *16*(3), 189-204. Retrieved from http://www.search.ebscohost.com

Wilcox, S., Schram, P., Lappan, G., & Lanier, P. (1991). *The role of learning community in changing preservice teachers' knowledge and beliefs about mathematics education.* East Lansing, MI: National Center for Research on Teacher Education. (ED330680)

Williams, S. R., & Baxter, J. A. (1996). Dilemmas of discourse-oriented teaching in one middle school mathematics classroom. *The Elementary School Journal, 97*(1), 21-38.

Withee, T., & Lindell, R. (2006). Different views on inquiry: a survey of science and mathematics methods instructors. *AIP Conference Proceedings, 818*(1), 125-128. doi: 10.1063/1.2177039

Yin, R. K. (2009). *Case study research: Design and methods*. (4th ed.). Thousand Oaks, CA: Sage Publications.

Zull, J. E. (2002). *The art of changing the brain: Enriching teaching by exploring the biology of learning*. Sterling, VA: Stylus Publications.

Appendix A

Follow-up Discussion Questions

Pedagogical practices

1. In both science and math methods classes we focused on the Learning Cycle. What role did the Learning Cycle play in your lesson development and implementation?
2. What specific teaching practices were you working on improving through the teaching of this lesson?

Processes for meaningful learning

3. What role did inquiry play in the lesson? In what ways do you feel you promoted inquiry?
4. What connections between mathematics and science did you want students to make? How did you design the lesson to promote students making those connections between mathematics and science?

Tools for conceptual development

5. In what ways did you use tools for conceptual development?
6. Would you use the tools differently next time you teach the same lesson? If yes, explain how you would use the tools differently. If no, explain why you would keep the use of the tools the same.

Appendix B

Final Reflection

1. How is math like teaching science? What is similar and what is different?

2. How would concrete tools/experiences play a role in a science lesson? Give examples.

3. How would concrete tools/ experiences play a role in a math lesson? Give examples.

4. Name and describe a few teaching strategies or approaches used to teach science for meaningful understanding.

5. Name and describe a few teaching strategies or approaches to teach math for meaningful understanding.

6. A. Think back to a math lesson that you taught during student teaching and briefly describe it.

   B. How do you think it met effective practice approaches to teaching? Explain.

CHAPTER 6: CONCLUSIONS

Summary

In conducting science and mathematics methods courses using common tools, processes, and approaches, preservice teachers' conceptions changed from the beginning of the methods course to the end of the methods course. Thirteen out of the twenty-two participants considered tools in science for hands-on learning initially. In contrast, only 6 of the participants initially recognized tools for hands-on learning in mathematics. By the end of the course, 17 of the preservice teachers recognized tools in science for building an understanding of concepts and 9 preservice teachers considered tools in mathematics for conceptual development. Participants articulated processes primarily in limited ways at the beginning of the semester. The design of the methods course and the field experiences bolstered their repertoire of processes for student engagement. Participants with more traditional views of science and mathematics teaching, in which the teacher delivered the knowledge, seemed to have a more difficult time accepting the learning cycle approach. Four preservice teachers in science and six participants in mathematics maintained a traditional approach for teaching science and mathematics. The participants with expanded views and progressive views seemed to accept the learning cycle approach in mathematics and science more easily; thought of tools in terms of conceptual development; and spoke of teaching in a manner that promoted reasoning, communication, and explanation by the end of the semester. By the end of the semester, 18 of the 22 participants recognized the learning cycle as a common approach to teaching science and mathematics. Table 7 provides detail of preservice teachers' conceptions of tools, processes, and approaches.

Table 7

Themes: Combined Chart

	Traditional	Expanded	Progressive
Tools			
Science			
Pre (n)	6	3	13
Post (n)	3	2	17
Mathematics			
Pre (n)	8	8	6
Post (n)	8	5	9
Processes			
Science			
Pre (n)	3	14	5
Post (n)	3	6	13
Mathematics			
Pre (n)	7	11	4
Post (n)	6	4	12
Approaches			
Science			
Pre (n)	7	6	9
Post (n)	4	7	11
Mathematics			
Pre (n)	8	9	5
Post (n)	6	5	11
Approaches between mathematics and science	No similarities in approaches	Partial connections	Recognizes similar approaches for both mathematics and science
Pre (n)	13	2	7
Post (n)	2	2	18

Two of the participants were followed into student teaching. At the end of methods these two seemed to have embraced the learning cycle as an approach for mathematics. However, their conceptions did not appear to be long-lasting. The lessons that they designed for their student teaching did not use the learning cycle approach. This could be attributed to the fact that they were in classrooms in which reform-based teaching was not the approach regularly used for mathematics teaching. After coaching by the researcher, they both altered their teaching to use reform-based mathematics lessons that followed a learning cycle. For Jane, this fit with the way she wanted to teach mathematics. For Kate, she was very uncomfortable and reverted to a more traditional style of teaching at the end of the observation time.

Tools for Conceptual Development

Methods Course Cases

Preservice teachers more readily accepted the use of tools for conceptual development in science than in mathematics teaching. Thirteen out of the twenty-two students thought that science should be taught with tools to help students see and understand the concept (see Table 7). They talked about tools in terms of hands-on learning, physical knowledge activities, and memorable concrete experiences. A typical response for initial thoughts of tools in science for understanding was, “Hands-on activities allow students to learn through experiences as well as trial and error. The concrete experiences are most of the time more memorable than lecture or book work so students often remember the information learned through experience more readily” (Person 3, Pre-test). By the end of the methods class, the few preservice teachers with a traditional view of the use of tools in science more easily accepted a hands-on approach to science teaching than mathematics teaching. They were also able to express the use of tools in science in terms of processes: “In science, concrete experiences help students observe and come to realizations. They allow students to make discoveries and construct knowledge” (Person 3, Post-test). By the end of the semester they also articulated tools in terms of concrete experience within their teaching practice:

> I taught Calcite Quest. The students had to search for evidence of calcite in various rocks. The student had concrete experiences in discovering what the evidence of calcite is and the searching for it. This was effective because students understood first-hand and were able to build on that due to comprehension. (Person 12, Post-test Methods Class)

Most of the preservice teachers initially thought of tools in science as a means for hands-on learning. Their work with students in the field verified the use of tools as a means to help students observe, connect with prior knowledge, and make realizations about science concepts.

Those with a traditional view of tools in mathematics were reticent to alter their conceptions of tools for mathematics teaching. Their personal school experiences as students were deeply embedded in their notions of teaching mathematics and likely affected their view of tools in mathematics. “To be honest, I never really had concrete mathematics experiences in school. My teachers always showed us methods to work problems on the board and that was it. It was all just memorization” (Person 9, Blog Methods Class). Some had very limited experiences in school with concrete materials for mathematics: “I only recall one experience in mathematics in school that I used concrete materials. It was in sixth grade and we were talking about geometry, shapes, and angles and we used geoboards as a concrete material” (Person 8, Blog Methods Class). Their mathematics lessons, although from hands-on curriculum, would often end up being taught in very teacher directed ways with the right answer being the sole purpose for the students in the lesson. However, almost all of the preservice teachers, who initially had a more expanded view and progressive view of tools for mathematics, were able to expand their ideas of tools in mathematics for the purpose of conceptual development. They already held ideas that mathematics should be interesting and creative for the students: “In a math lesson students can use the concrete tools or manipulatives to actually see the math lesson unfolding.

The students will have the numbers as a concrete thing" (Person 20, Pre-test). The use of tools for concept development rather than for right answers fit in with their existing notions.

Student Teaching Cases

Jane began methods class with a view of tools in science for hands-on learning and tools in mathematics for students to "see" and "do" the mathematics. The methods class reinforced her ideas of how tools should be used for science and mathematics teaching: "When discussing topics that can be experimented, the children need to actually see it and get involved instead of just listening about it" (Jane, Pre-test Methods Class). Tools for conceptual development fit with her notions of science as a hands-on subject. Tools in mathematics also offered a means for students to understand the mathematics. Furthermore, her lessons in the field demonstrated effective use of tools for conceptual development.

Kate entered methods class with very different ideas from Jane in the use of tools in mathematics and science. She saw the use of tools in science as students seeing concepts from the textbook: "Concrete tools and experiences allow the students to see the concepts that they read about using textbooks applied in a tangible way" (Kate, Pre-test Methods Class). Tools in mathematics were thought of in limiting terms of real-world mathematics such as time and money. "When you relate mathematics to real-life situations, like counting money or telling time, they are more likely to become engaged" (Kate, Pre-test Methods Class). She seemed to try to justify traditional modes of science teaching throughout her science methods:

> There are times that call for more traditional instruction, but as long as the teacher keeps it interesting and incorporates hands-on activities where it is possible, the students will have an enjoyable, meaningful, learning experience. (Kate, Blog Methods Class)

However, in her mathematics teaching she described the importance of using tools in mathematics:

> Many students do not gain understanding by simply watching the teacher do a problem in the board. Most students learn more easily and retain more information if they discover the concepts on their own, and often times the best way to get students to explore and discover new ideas is through working with concrete materials. (Kate, Blog Methods Class)

Although, Kate's mathematics lessons were very controlled and she sometimes would tell students answers instead of waiting for them to figure it out, she did use a variety of tools for students to understand the mathematics concept. During methods class she used tools to teach patterns, geometry, data, and money:

> The first day I taught the investigation lessons in which the students stood as long as they could on one foot with their eyes closed. Then they placed their times on the line plot and compared the group data. The second lesson I taught dealt with comparing the ages of students and adults they knew which built on simply observing individual data with group data because the students had to observe the several relationships between the data. Concrete experiences were crucial in each of the activities. The students actually stood on one foot with their eyes closed in the first activity, and placed their times on an enlarged plot on the wall. In the second activity, the students used cash register paper strips to compare the different sizes between their "life strips" and the adult "life strips". This made the math terms such as "times as much as" make more sense. (Kate, Blog Methods Class)

Based on how Jane and Kate ended their methods class, it was expected that they would be using tools in their mathematics teaching during the student teaching experience. However, the first lessons that were observed were very traditional in nature with the teacher explaining and the students working problems. Tools were used for procedures rather than conceptual understanding. In Jane's first and second lessons, students were practicing using a ruler to measure objects. In Kate's first lesson, students completed a series of games to build automaticity of facts. Through the conversations after the lessons, the researcher was able to recall how and why tools were used for concept development in mathematics. Jane altered her teaching to include more of a variety of tools to help students understand concepts. Although her initial lessons were procedure focused, with a little coaching she was able to develop and implement lessons that used tools for students to "see" and "do" the mathematics. In one lesson she used student data, an interactive website, and tiles to help students understand representations of data. In another lesson she used fraction magnets on the board, farm animal toys on the document camera, and fraction circle sets with the students as a means of fostering understandings of fractional concepts. She embraced the use of tools for conceptual development due to the dissatisfaction of her own school experiences in mathematics:

> I agree with letting students figure things out on their own. When a teacher tried to drill things in my head, it always made me feel like I had no freedom to do what I wanted to do. It put more pressure on me because I felt like I had to do it just like everyone else. I honestly think I would have done a lot better in math if I were given this choice in school. Math is so flexible and there is no reason that you should have to do something one way. (Jane, Blog Methods Class)

Kate also changed her lesson plans to teach more hands-on lessons. However, Kate's use of tools was still within a controlled teacher context. She also would give students answers rather than giving them time to figure information out based on the observations and mathematical relationships the students had learned from the tools.

Processes for Meaningful Learning

Methods Course Cases

Three preservice teachers thought of science processes in traditional ways and seven preservice teachers thought of processes in mathematics in traditional ways at the beginning of methods class (see Table 7). Traditional conceptions placed the students in passive roles with the teachers giving all of the information. A typical statement for traditional processes in science was, "Teach a lesson, do the activity, let students explain how it worked and how they go together" (Person 4, Pre-test). A typical statement for traditional processes in mathematics was, "Teach the lesson, work together as a class and have students work independently" (Person 4, Pre-Test). In these scenarios the students are following the examples provided by the teacher. The students are not involved in problem solving. "Problem solving means engaging in a task for which the solution method is not known in advance" (NCTM, 2000, p. 52). In both scenarios, students are completing a science or mathematics lesson in which the method has been given by the teacher. Since the method is known, they are, therefore, not reasoning, communicating, or making connections about the mathematics or science. There were 3 more preservice teachers who thought of mathematics processes in traditional ways than those who thought of science in traditional ways by the end of the semester.

Most of the preservice teachers articulated processes for science in expanded ways at the beginning of the methods classes. Fourteen preservice teachers held expanded views of processes in science and 11 preservice teachers held expanded views of processes in mathematics at the beginning of the methods classes. Expanded conceptions were indicated as ideas of process that were more than just students serving in a passive role but not as deep as concept development. The most change occurred with those who had expanded conceptions of processes in mathematics. They deepened their understanding to think about processes in mathematics for students to develop reasoning skills. In their mathematics teaching tools became a means to help students with processes:

> I did an activity called Shifty Shapes which allowed the students to explore shape composition. The students used pattern block cut-outs to create solutions to completely cover the hexagons. The students understood the small shapes could be assembled to make the larger shape. The students were able to solve the problems with different shapes. They had tor make sure their solutions would completely cover the hexagon. (Person 21, Blog Methods Class)

Conceptions in which processes in science and mathematics focused on problem solving, reasoning, communications, making connections, or developing representations were progressive. On the pre-test they referred to students finding meaning through hands-on teaching: "Experiment and hands-on inquiry allow students to use trial and error to find meaning and understanding" (Person 3, Pre-test). Thirteen of the preservice teachers with expanded views at the end of methods class recognized processes for students to reason and figure out concepts for themselves. In one lesson students had to figure out how to communicate on Mars. In the lesson the teacher promoted problem solving, communications, and reasoning:

> The lesson I taught was on Friday, which was the day that they got to make communication devices. I had to explain to them that there is no air in Mars and sounds

> need a way to travel. I also explained to them that the inconvenience with radio waves in space and all of the problems associated with trying to get the internet in space. They got to brainstorm and come up with a way to communicate while on Mars. I could see that they learned a lot through these activities because of the questions that were asked while they worked. (Person 17, Blog Methods Class)

They articulated processes in their lessons as students making connections, using observations to draw conclusions, and justify their reasoning. By the end of methods classes, 13 of the participants in science and 12 of the 22 preservice teachers in mathematics conceived of processes in progressive ways.

Student Teaching Cases

Jane began methods class with conceptions of students actively involved and figuring out the mathematics and science: For science she believed that: "The children need to actually see and get involved instead of just listening about it" (Jane, Pre-test Methods Class). She felt similarly in mathematics: "Again the students need to "see" and "do" to learn in math. It helps them get a better understanding of how math really works instead of just plugging numbers into formulas" (Jane, Pre-test Methods Class). Methods class deepened her conceptions to include not only reasoning for students but the use of communication between students to develop understanding. She used questioning techniques to help students to think about the mathematics:

> I taught a measuring capacity lesson to K-2 students. They began by learning how to count, record, and measure how many spoonfuls of rice o took to fill up a small party cup. The first time they all got different numbers. I asked them to look at the numbers and tell me what they noticed about them. They couldn't understand why everyone's was so different because they all had the same cup and spoon. Then I began to ask them how

they measured. For example, how big a spoonful they used or what they called a full cup. This began the inquiry stage. They began thinking about why it was so different. So we established a certain way everyone was going to measure. This time they all got around 25 and 30. They were so amazed at how it worked. (Jane, Blog Methods Class)

Kate considered processes initially as students serving in passive roles while the teacher imparted the knowledge. In science she initially believed that students used processes to understand the textbook content: “Experiences allow students to see the concepts that they read about in the science book” (Kate, Pre-test Methods Class). By the end of the semester she believed that students should be allowed freedom to explore concepts in science under teacher direction: “ Some useful techniques for science include encouraging students to make predictions based on prior knowledge, and then allowing them free exploration so they can discover concepts on their own (w/ teacher scaffolding) [*sic*]” (Kate, Post-test Methods Class). She expanded her notions for students to reason and make connections. In a lesson that she taught on patterns, students used pattern blocks to continue the iteration of the pattern. With every iteration the pattern would grow and the students recorded how many blocks were in the iteration. She had the students continue the pattern and record. The students were supposed to figure out the 100^{th} pattern based on what they noticed. When they didn’t figure it out right away, she told them the answer. Her need for continuous control limited the reasoning and connection-making for the students in the lessons she taught during methods class.

At the beginning of their two weeks of full-time student teaching, both Jane and Kate focused on processes for right answers. Jane’s lesson focused on using a ruler and Kate’s lesson focused on basic multiplication facts. They seemed to have forgotten the methods class instruction of fostering processes for science and mathematics to develop conceptual understanding. When they altered their mathematics lessons to include more investigation type mathematics lessons, students were required to reason, communicate, and explain their understandings due to the nature of hands-on mathematics lessons. In the data lesson, that Jane taught, her students used various representations to understand graphs: “So our bar would represent our categories. Let’s try this again. What would our bar graph look like from this morning? So you have seen the circle graph. Now let’s look at the bar graph. Does anyone have a prediction?” (Jane, O, 4/16). In her fraction lessons, students used pattern blocks, fractions circles, and fraction magnets on the board to “see” and “do” the mathematics. After one of the fraction lessons in which students used pattern blocks to make cookies she felt she promoted processes, “when they were putting together the hexagon. They had to figure it out, to put it together themselves” (Jane, FI, 4/22).

In Kate’s teaching, processes even within investigation lessons were limited due to her controlled style of teaching. She changed her original plans to teach the tower investigation. Even though she followed the frame of the lesson, she would not give students time to figure out the mathematics. In the first example, she showed the tower to the students and asked them to make predictions about what number will end up at the top of the tower. Then she tells the student the pattern instead of letting them figure it out:

> The tens place does seem to go up by 30 and 20 ignoring the ones place. Look at the numbers you predicted. Most of you picked numbers that made sense. They all ended in 5 and 0. If we look at the bottom it is like 1x 25, 2x 25. (Kate, O, 4/21)

In the same lesson she does a few multiplication and division problems using the tower. The students are supposed to use the tower to solve the problems. If the lesson is followed, students understand the inverse relationship between multiplication and division. They then develop ways to reason and figure out the answers using number sense. However, in Kate's lesson she tells them how to think and move on the tower:

> That's what we mean when we divide. It doesn't always come out evenly and we have a remainder. I am going to try to trip you up. 420 divided by 25. [Kate counts up to 400]. 425 is too many so we will stop here. [Kate draws a line at 400]. How much over 420 is 425? (Kate, O, 4/21)

Pedagogical Approaches

Methods Course Cases

Interpretations of Hands-on Approach. Pedagogical approaches were categorized as traditional view, expanded view, or progressive view (see Table 7). Participants with a traditional view followed the notion that the teacher explains and the students complete verification activities in science and mathematics. Initially seven participants in science and eight participants for mathematics held traditional views. Throughout their blogs, they focused on teachers explaining and students giving right answers:

> It is very important that the hands-on activity is clearly explained and applied… It is best to first have students learn information and then assess or reinforce with a hands-on activity…Flash cards help students in remembering key facts to build upon…I listened carefully to their conversation to hear student thinking to determine whether or not their thinking would lead them to a correct answer. (Person 3, Blog Methods Class).

Four participants in science and six participants in mathematics who conceived of teaching mathematics and science with a traditional approach initially had little change by the end of the methods class.

Six of the participants in science and 9 of the participants in mathematics initially held an expanded view of teaching science and mathematics. They described science and mathematics as more than the teacher delivering the knowledge, but not on the level of approaching science and mathematics for conceptual understanding: “Having learning centers for children to learn or review different science centers” (Person 10, Pre-Test Methods Class). In mathematics, they believed that the approach should focus on real-life mathematics and centers: “Real-life projects have value in everyday life like counting money. Role play like grocery store” (Person 14, Pre-test Methods Class).

By the end of the semester seven people were categorized with an expanded view in science and five in mathematics. The additional person in the expanded category for science can be explained by some of the participants in the expanded category moving to the progressive category and some of the ones with a traditional view moving to the expanded view.

Nine of the participants were categorized as progressive for science and five were categorized as progressive for mathematics. Those with a progressive view initially expressed that science and mathematics should be taught with a hands-on approach:

> [For science teaching] Use learning centers, group activities, and hands-on activities for example when you are teaching about insects and plants have the students go outside and see these insects and plants hands-on. [For mathematics teaching] Group work, hands-on approaches and everyday uses. For example when teaching division, bring in a cookie and ask students how will everyone get a piece, and allow the students to think about and use their knowledge on how to divide the cookie. (Person1, Pre-test Methods Class)

For those with expanded or progressive views at the beginning of methods courses, their beliefs seemed to fit reform-based practices on use of hands-on for science and mathematics teaching.

By the end they often referred to approaching both science and math with the learning cycle approach:

> Teaching math is like teaching science in several ways. Each subject needs a "hands-on" approach to learning the material through experience. Teachers in both subjects need to provide students with concrete materials to explore how things work. The 5E's is a great model to use for approaching science teaching. It provides instruction at all levels, all the way from engagement and evaluation. The 5E's can be used in math just as in science. (Person 19, Post-test Methods Class)

Interpretations of the Learning Cycle Approach. Although 18 of the preservice teachers did indicate that the learning cycle approach was a good approach for science and mathematics at the end of the semester, they were unfamiliar with the learning cycle initially. In the learning cycle student exploration precedes explanation and definitions of terms. With the learning cycle approach exploration provides the base for developing an understanding of concepts. This is different from the inform-verify-practice model of teaching. Preservice teachers interpreted the use of the learning cycle in different ways throughout the semester. In the blogs, the preservice teachers described their understanding of the learning cycle. They felt that the learning cycle helped students relate to what they were learning through the use of first-hand experiences:

> During the learning cycle students also learn to become problem solvers which help them to become more autonomous as adults. Another benefit of the learning cycle is that it allows students to relate new ideas about science to their experiences associated with it. I believe that through the learning cycle stages students learn more and are better able to

> construct and relate knowledge from their firsthand experiences compared to just copying definition and writing notes. (Person 19, Blog Methods Class)

The few who held to more traditional modes of teaching were conflicted with the idea of the students exploring before explanation. “I think the traditional approach needs to be kept in the curriculum, along with the learning cycle approach” (Person 2, Blog Methods Class). Those who held to more traditional roles of mathematics teaching saw the learning cycle as steps to follow in mathematics. Their steps often mirrored the teacher explains and the students solve problems. Solving problems is not the same as problem solving. In problem solving the method of finding the solution is not known initially. Those who saw the learning cycle as steps also believed that students working who were working in groups were also exploring. This is not exploration if students are solving routine problems: “I believed playing a short clip or film would be good to show the students during the engage part of the lesson. Then in the explore part we should allow students to work problems to solve as a group” (Person 10, Blog Methods Class). A majority believed the learning cycle in mathematics created an environment that allowed students time to develop understandings about mathematics:

> If you don’t get one concept, there is no way that you are going to understand and be able to comprehend things on a higher level. Thus is true for a lot of students. Teachers get wrapped up and in a hurry and don’t really allow time for the students to think or fully understand something before moving on to something totally different! The LC is a good way, I think to keep teachers in line and on the right track for student learning, especially in math. (Person 22 Blog Methods Class)

By the end of the methods class, 18 of the beginning teachers thought that the learning cycle was a common approach for both science and mathematics teaching. A typical response was “teaching math and teaching science both relate to the learning cycle, 5E’s and very important assessment strategies for the classroom” (Person 20, Post-test Methods Class).

Student teaching Cases

Jane entered methods class with the notion that science involved hands-on experiments and that mathematics should be taught with games and hands-on activities. Her ideas of how science and mathematics should be approached were consistent with her notions of tools for students to “see” and “do”. In order for students to “see” and “do”, the use of hands-on teaching provided a means for students to reason and understand the concept. Methods class reinforced her conceptions of tools, processes and ultimately approaches to teaching science and mathematics. By the end of the methods class she thought that mathematics was like science in that, “they both involve inquiry, 5E learning cycle, and hands-on activities” (Jane, Post-test). When asked on the post-test to describe a math lesson she had taught and explain how it met effective approaches, she responded:

> I taught a lesson on measurement and capacity with K-2 grades. I taught them how to measure with non-standard approaches. I had them guess how many spoonfuls of rice it would take to fill their cup. This involved inquiry. Then I had them explore and fill it once. We then discussed and made second guesses (more inquiry). We then discussed measurement concepts. They then did experiment 2 using what we discussed. (Jane, Post-test Methods Class)

Kate began methods class with mixed views on her pre-test. For tools in science she said tools were to enhance concepts in the science book. Then when asked about approaches, she said hands-on was the approach for science. Her response about tools actually reflected her true ideas about science teaching. Her science blogs discussed hands-on but in terms of a treat for students or something a teacher does if she has time. Her pedagogical approach fit with her notions of tools in science as a means of enhancing the concepts in the science book as well as processes for answers. She held very traditional ideas about science teaching. She grappled with accepting a more hands-on science approach throughout the science methods class: “I also know that there are other times that call for more traditional instruction, but as long as the teacher keeps it interesting and incorporates hands-on where it is possible, the students will have an enjoyable, meaningful learning experience” (Kate, Blog Methods Class). By the end of the semester, she conceived of teaching science with hands-on lessons as a reward or treat for the students for good behavior. Her approach for teaching science also limited processes for students. Teaching from the science book limited her students to processes articulated for textbook answers.

She viewed approaching mathematics in terms of relating mathematics to real-life. Her view of ‘the teacher explains and students see examples’ also fit with her ideas of mathematics teaching. In math, her students were still limited to using tools for procedural ways and focusing on right answers in mathematics. She expanded her approach for mathematics to include hands-on but only in limited terms of real-world mathematics. When asked on the Post-test to describe a math lesson she taught that met effective approaches, she wrote, “I taught the Shapes on the Bus activity, which had students relate their knowledge about shapes to everyday objects. The students created their own school buses” (Kate, Post-test Methods Class).

By the end of the methods class, both Jane and Kate believed that the learning cycle was an approach for teaching science and mathematics that also involved inquiry-embedded teaching. Although Kate said that the learning cycle was an approach for science and mathematics, this was not how she would approach science and mathematics. In her first science blog she seemed to grapple with the notion that explanation followed hands-on learning. By the end of her science methods class she described hands-on in science as something students could work towards. Her blogs revealed that she maintained a more traditional approach for teaching science with hands-on as reward. She did see mathematics as being taught with hands-on approaches for students to learn and understand real-world mathematics. The explore aspect of the learning cycle fit with Kate's ideas for approaching mathematics. Jane, on the other hand, seemed committed to the learning cycle approach for both science and mathematics. This approach fit in with her notions of students being able to "see" and "do" to develop their learning.

Based on the data from the end of methods class it was expected that Jane would incorporate more of the learning cycle approach in mathematics than Kate. However, their first lesson observation indicated that neither one of them had considered the learning cycle approach in their mathematics lessons. After debriefings with Jane in which the learning cycle as an approach for mathematics was the topic, she made changes in her lessons to incorporate more of the learning cycle in her mathematics teaching. Jane did include exploration and engagement with various materials. Kate also altered her lesson plans to include more hands-on mathematics teaching. Her lessons had limited engagement, explorations, and elaborations. Her need to control the lesson, along with the lack of think time for the students to think about the concepts, limited student learning.

Although Jane and Kate articulated hands-on for mathematics teaching at the end of methods class, this did not carry over into their student teaching experience. They both approached mathematics with a traditional style of teaching. They may have been mirroring how the cooperating teacher approached mathematics teaching. They did alter their lessons upon the prompting of the researcher to include more hands-on learning. The first two lessons observed for Jane were for measurement practice using a ruler. The first follow-up conversations focused on management issues she was having with students. Part of her management problems were due to student boredom. The rest of the follow-up conversation focused on improving the quality of the mathematics and using resource based materials. The third lesson seemed to be the turning point for Jane in the implementation of the lesson that matched how she wanted to approach mathematics. For Jane, this inclusion of hands-on fit her ideas of students being able to “see” the concept.

Kate’s initial lesson was on multiplication facts. The follow-up discussion with Kate revealed that she was moving into division. I discussed the number towers and how they were designed to foster students’ understanding of the relationship between multiplication and division:

> Kate was teaching an Investigation lesson for the first time. It was obvious in her mannerisms that she was timid about this lesson. It is not a traditional approach to division where students learn the division algorithm. This way of approaching division is probably foreign to the way she learned multiplication and division. (Researcher Journal, 4/21)

Kate incorporated more hands-on in some of her lessons but appeared to be very uncomfortable in teaching those lessons. By the end of her two-weeks she reverted back to a traditional style of mathematics teaching and appeared to be more at ease. At the end of the week she had students complete a series of various procedural problems. The ones who finished early were allowed to get up and solve problems with the number towers. However, in the follow-up discussion this is how she described her approach for the lesson, “Explore. I feel they had to look at the division problem and look hard and ask “What tools do I have” How can I figure it out based on what I know?” (Kate, 4/23). Although she talked about students exploring in the lesson she never asked the students about their findings with the towers. Her description of her approach and what actually occurred were glaringly inconsistent. When using reform-based materials, it is important to provide avenues for student to build bridges and make connections. Teachers have to probe and find out about student thinking. Perhaps Kate will develop this in her teaching practice as she gains experience.

Final Note

Understanding preservice teachers' conceptions of tools, processes, and approaches is important in teacher education. Preservice teachers' conceptions of the use of tools often represented their views of processes and approaches. Some would mention hands-on as the approach they would use but their description of tools indicated a teacher-directed style of teaching. With the learning cycle approach, tools serve as a means for connecting to prior knowledge and promoting understanding of new knowledge. Preservice teachers would use the phrase "hands-on" to describe their teaching, but this does not mean they viewed hands-on as intended by the learning cycle approach. Additional research needs to be conducted to determine what preservice teachers mean by "hands-on" for science and mathematics teaching.

Since tools are thought of as a necessary component of science teaching, the question then becomes, "How can teacher educators help preservice teachers see tools in mathematics as being necessary for understanding as well?" Planning and developing mathematics courses throughout the preparation program that use an inquiry-embedded approach would be one means of establishing tools in mathematics for inquiry-embedded teaching. This would require cooperation on the part of the teacher educators and mathematicians at institutions.

Another way to foster development of preservice teachers thinking and practice would be through the use of blogs. In this research the preservice teachers wrote their blogs and responded to blogs by other preservice teachers. If the methods professors had also participated in the blogs, asking questions, providing responses, and becoming part of the conversation, this may have added another dimension to the development process. Although time on campus served as an opportunity to teach concepts and help clarify misconceptions, the professors' involvement in the blogs may also have provided a means to teach and clarify conceptions. In some of the blogs conceptions held by preservice teachers were unclear. In the response blogs, the professors also could have asked the preservice teachers to explain and clarify their thinking.

The intersection of technology, pedagogy, and content knowledge through the blogs provided a means for preservice teachers to express their understandings or misunderstandings. The blogs were an assignment intended to help the instructors gain insight into preservice teacher thinking. The blogs could have been used more directly in the methods classes as a model for reflective thinking. Ideas expressed in the blogs could have been used for further discussion in class. This might have been helpful for those who had notions of inquiry that weren't true inquiry. Group discussion could have served as another means for clarification. Discussion of the blog itself could have helped the preservice teachers think about technology use for instruction as well. Furthermore, it would have been ideal if the student teachers continued to blog about math during their student teaching and responded to each other. This might have provided additional insight into their development as mathematics teachers.

Following the two preservice teachers beyond the methods course into student teaching revealed that the nature of their understandings and conceptions of teaching mathematics from the start of methods class had changed little by the time they entered the student teaching experience. The change that appeared to have occurred at the end of methods class could be for several reasons. First of all, the students were immersed in the learning cycle as an approach to teaching science and mathematics during the methods class. Furthermore, they may have liked the idea of using the learning cycle in mathematics. However, when it came time for them to plan and implement mathematics lessons in student teaching, they reverted back to a style of mathematics teaching that they had experienced in school and that their cooperating teacher supported.

True change in thinking that impacts practice occurs over time. The time it takes to complete a methods course, and with limited practice, is not enough time for people to change years of experience as students in traditional classrooms. Those who shifted their thinking from the beginning of methods class to the end, shifted in ways that fit with their expectations and notions for what teaching mathematics should be like. The few students who held traditional conceptions of tools, processes, and approaches at the onset of methods course had very little change by the end. This indicates that it may be even more difficult to alter the conceptions of those with deeply held traditional perspectives. Kate leaned more toward the traditional approaches than Jane initially. Even in her student teaching, although she tried to teach lessons with a different approach, her comfort was in a traditional approach. Kate may be viewed as a good teacher because she had excellent classroom management. However, her need to direct and inform the students of how to think and solve problems interfered in students figuring it out for themselves. However, Jane really wanted to teach in a manner that made the concepts easier for students to understand. Her vision she expressed at the beginning of methods class stayed with her into her student teaching. For the case of Jane, she improved in her teaching after some guidance in teaching hands-on lessons.

In order for a person to achieve conceptual change they must become dissatisfied with their existing notions (Posner et al., 1982). Kate demonstrated how well she was able to perform the assignments required during her methods courses. This gave the impression at the end of the semester that she had embraced the learning cycle. However, Kate was not dissatisfied with the way she learned in school. The teacher-directed approach worked for her. Kate appeared to place her trust in a teacher-directed approach for teaching mathematics in her student teaching. Jane, however, indicated strong feelings for the manner in which she was taught mathematics. She was dissatisfied with a teacher-directed approach. It was very important to Jane that students learn for themselves through experience.

This research also indicated a need to rethink qualities that make methods students appear to be strong teachers. Jane completed her assignments during methods classes but was not considered as strong of a student as Kate. This indicated that those who are perceived as being strong methods students may not actually be strong methods students in teaching through reform-based approaches. They may be good at school. Following them through student teaching then becomes an important part of teacher education to provide continual support for the novice teachers.

The teaching approaches of the methods class needs to follow preservice teachers as they enter student teaching. A working relationship with cooperating schools and cooperating teachers would help both parties in the development of the beginning teachers. The learning cycle from the outside appears to be easy to use in teaching. However, perhaps it is more difficult to implement for new teachers. In the case of Jane and Kate, they reverted to more traditional styles of teaching upon taking on the responsibility of full-time teaching. Placing preservice teachers in classrooms that use the learning cycle may yield different outcomes.

Finally, the researcher's role as a coach in teaching mathematics was effective in the both cases. The follow-up conversations provided a time to recall and discuss methods of mathematics teaching. Sometimes discussion focused on resources and lessons that would be applicable to the objectives they had to teach. Other conversations focused on management of an investigative type lesson. Both student teachers changed and altered their lesson plans to teach investigative type lessons. Jane bloomed as a math teacher when she made this change. Kate tried teaching the lessons but was very uncomfortable and would not give the students freedom in thinking. The fact that she was willing to try something outside of the norm for her student teaching experience indicates she is willing to try new methods of teaching. Perhaps as she gains experience she will become more flexible in her teaching style. Further research needs to be conducted as elementary teachers move through the teacher preparation process that uses the learning cycle approach into full-time teaching.

References

Abraham, M. R., & Renner, J. W. (1983). *Sequencing language and activities in teaching high school chemistry: A report to the National Science Foundation*. Washington, D.C.: National Science Foundation. (ED241267)

Adami, M., & Kiger, A. (2005). The use of triangulation for completeness purposes. *Nurse Researcher*, *12*(4), 19-29. Retrieved from http://search.ebscohost.com

Adams, N., Cooper, G., Johnson, L., & Wojtysiak, K. (1996). *Improving student engagement in learning activities*. (Unpublished master's thesis). Saint Xavier University. Retrieved from Eric database. (ED400076)

Akerson, V. L. (2005). How do elementary teachers compensate for incomplete science content knowledge? *Research in Science Education, 35*(2-3), 245-268. Retrieved from http://www.eric.ed.gov

Akerson, V. L., & Donnelly, L. A. (2008). Relationship among learner characteristics and preservice elementary teachers' views of nature of science. *Journal of Elementary Science Education*, *20*(1), 45-58. Retrieved from http://www.eric.ed.gov

Alsup, J. K. (2003). New classroom rules to promote preservice elementary teachers' mathematics learning. *Education, 123*(3), 609-615. Retrieved from http://search. ebscohost.com

American Association for the Advancement of Science [AAAS] (1993). *Benchmarks for science literacy*. Retrieved from http://www.project2061.org/ publications/bsl/online/ index. php?txtRef =&txtURIOld=%2Fpublications %2Fbsl %2Fonline %2Fbolintro%2Ehtm

American Educational Research Association [AERA]. (2004). *Guiding standards: Research populations, educational institutions, and the public*. Retrieved from http://www. aera.net/aboutAERA/Default.aspx?menu_id=90&id=174

Anderson, C., & Hoffmeister, A. M. (2007). Knowing and Teaching Middle School Mathematics: A Professional Development Course for In-Service Teachers. *School Science & Mathematics*, *107*(5), 193-203. Retrieved from http://search.ebscohost.com

Appleton, K. (2008). Developing science pedagogical content knowledge through mentoring elementary teachers. *Journal of Science Teacher Education*, *19*(6), 523-545. Retrieved from http://www.eric.ed.gov

Appleton, K., & Kindt, I. (1999, March). *How do beginning elementary teachers cope with science: Development of pedagogical content knowledge in science*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Boston, MA. Retrieved from ERIC database. (ED448998)

Association for Childhood Education International [ACEI]. (2007). *Elementary education standards and supporting explanation*. Retrieved from http://acei.org/wp-content/uploads/ACEIElementaryStandardsSupportingExplanation.5.07.pdf.

Atkin, J. M., & Karplus, R. (1962). Rebuilding the science program. *The Science Teacher, 29*(5), 45-51.

Atkinson, R. D., & Mayo, M. (2010). *Refueling the U.S. innovation economy: Fresh approaches to science, technology, engineering, and mathematics (STEM) education*. Washington, D.C.: Information Technology and Innovation Foundation. Retrieved from ERIC database. (ED521735)

Bales, B. L., & Mueller, J. J. (2008). Preparing teachers for a new era: Building bridges in the learning-to-teach professional sequence. *The New Educator, 4*(2), 152-168. Retrieved from http://seacrh.ebscohost.com

Ball, D. L. (1988). *Research on teaching mathematics making subject matter knowledge part of the equation*. Retrieved from ERIC database. (ED301467)

Ball, D. L. (1996). Teacher learning and the mathematics reforms. *Phi Delta Kappan*, *77*(7), 500. Retrieved from http://search.ebscohost.com

Banchoff, T. F. (2000). The mathematician as a child and children as mathematicians. *Teaching Children Mathematics*, *6*(6), 350. Retrieved from http://search.ebscohost.com

Batesky, J. (2001). Thoughts on practice of teaching: A professor's experience. *Contemporary Education*, *72*(1), 53-57. Retrieved from http://search.ebscohost.com

Bhattacharyya, S., Volk, T., & Lumpe, A. (2009). The influence of an extensive inquiry-based field experience on preservice elementary student teachers' science teaching beliefs. *Journal of Science Teacher Education*, *20*(3), 199-218. Retrieved from http://search. ebscohost.com

Battista, M. T. (1999). The mathematical miseducation of America's youth. *Phi Delta Kappan*, *80*(6), 424. Retrieved from http://search.ebscohost.com

Beeth, M. E., Hennesey, M. G., & Zeitsman, A. (1996). *Teaching from a constructivist paradigm: A way of knowing and learning or a case of "pedagogical tricks?"*. Retrieved from ERIC database. (ED407269)

Beeth, M. E., & McNeal, B. (1999). *Co-teaching mathematics and science methods course*. Retrieved from ERIC database. (ED443666)

Bell, G. L. (2001, January). Reflective journal writing paired with inquiry-based science instruction: Effects on elementary pre-service teachers' science and science teaching beliefs. *Association for the Education of Teachers in Science: Proceedings of the AETS Conference,* Costa Mesa, CA (pp.1-18). Retrieved from http://www.eric.ed.gov

Berlin, D. F., & White, A. L. (1991). A network for integrated science and mathematics teaching and learning: NCSTL monograph series #2. Retrieved from http://www.eric.ed.gov /PDFS/ED349167.pdf

Beyer, C. J., & Davis, E. A. (2008). Fostering second graders' scientific explanations: A beginning elementary teacher's knowledge, beliefs, and practice. *The Journal of the Learning Sciences, 17*(3), 381-414. Retrieved from http://search.ebscohost.com

Bianchini, J. A., & Cavazos, L. M. (2007). Learning from students, inquiry into practice, and participation in professional communities: beginning teachers' uneven progress toward equitable science teaching. *Journal of Research in Science Teaching*, *44*(4), 586-612. Retrieved from http://search.ebscohost.com

Bircher, L. S. (2009). Reading aloud: A springboard to inquiry: Trade books in the science classroom. *The Science Teacher*, *76*(5), 29-33. Retrieved from http://search.ebscohost. com

Bleicher, R.E. (2006). Nurturing confidence in preservice elementary science teachers. *Journal of Science Teacher Education*, *17*(6), 165-187.

Boddy, N., Watson, K., &Aubusson, P. (2003). A trial of the 5Es: A referent model for constructivist teaching and learning. *Research in Science Education, 33*(1), 27-42. Retrieved from http://search.ebscohost.com

Bogdan, R. C., & Biklen, S. K. (1982). *Qualitative research for education: An introduction to theory and methods*. Boston, MA: Allyn & Bacon

Bolton, C. (1997, February). *Developing teachers: A novice-expert study of initial teacher preparation.* Paper presented at the 49th Meeting of the American Association of Colleges for Teacher Education, Phoenix, AZ. Retrieved from ERIC database. (ED405335)

Brown, D. E., & Clement, J. (1989, March). *Overcoming misconceptions via analogical reasoning: Factors influencing understanding in a teaching experiment*. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA. Retrieved from ERIC database. (ED307118)

Brown, P., Freidrichsen, P., & Mongler, L. (2008). 2-Liter bottles and botanical gardens: Using inquiry to learn ecology. *Science Activities*, *44*(4),153-157. Retrieved from http://www. eric ed.gov

Bruner, J. S. (1968). *Processes of cognitive growth: Infancy*. Worcester, MA: Clark University Press.

Bull, G., Bull, G., & Kajder, S. (2003). Writing with weblogs. *Learning & Leading with Technology*, *31*(1), 32-34.

Bybee, R.W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Cady, J., Meier, S. L., & Lubinski, C. A. (2006). Developing mathematics teachers: The transition from preservice to experienced teacher. *The Journal of Educational Research*, *99*(5), 295-305. Retrieved from http://search.ebscohost.com

Cannizzaro, L., & Menghini, M. (2006). From geometrical figures to definitional rigour: Teachers' analysis of teaching units mediated through Van Hiele's Theory. *Canadian Journal of Science, Mathematics, and Technology Education*, *6*(4), 369-386. Retrieved from http://search.ebscohost.com

Cardak, O., Dikmenli, M., & Saritas, O. (2008). Effect of 5E instructional model in student success in primary school 6th year circulatory system topic. *Asia-Pacific Forum on Science Learning and Teaching*, 9(2), Retrieved from http://search.ebscohost.com

Castro, A. (2006). Preparing elementary preservice teachers to use mathematics curriculum materials. *Mathematics Educator*, 16(2), 14-24. Retrieved from http://search.ebscohost .com

Cathcart, W. G., Pothier, Y. M., Vance, J. H., & Bezuk, N. S. (2006). *Learning mathematics in elementary and middle schools: A learner-centered approach* (4th ed.). Saddle River, NJ: Pearson Merrill Prentice Hall.

Charmaz, K. (2005). Grounded theory in the 21st Century: Applications for advancing social justice studies. In N. K. Denzin, & Y. S. Lincoln (Eds.), *The Sage handbook of qualitative research* (3rd ed.). (pp. 507-535). Thousand Oaks, CA: Sage Publications.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. Thousand Oaks, CA: Sage Publications.

Chessin, D. A., & Moore, V. J. (2004). The 6E learning model: The "E-search" adds a modern component to the popular 5-E learning model. *Science and Children*, *42*(3), 47-49.

Chick, H. L. (2007). Teaching and learning by example. In J. Watson & K. Beswick (Eds.) *Mathematics: Essential Research, Essential Practice. Volumes 1 and 2. Proceedings of the 30th Annual Conference of the Mathematics Education Research Group of Australasia, Adelaide, SA* (pp. 3-21). Mathematics Education Research Group of Australasia. Retrieved from http://www.eric.ed/gov

Clark, I. (2003). Soils ain't soils. *Investigating: Australian Primary and Junior Science Journal*, *19*(4), 13-16. Retrieved from http://search.ebscohost.com

Clark, J. (2005). Achieving teacher education standards through a mathematics performance-based assessment: A case study of five Colorado preservice teachers on field experience. *International Education Journal*, *5*(5), 55-70. Retrieved from http://search.ebscohost.com

Common Core State Standards Initiative. (2010). *Common core standards initiative standards-setting considerations*. Retrieved from http://www.corestandards.org/assets/Considerations.pdf

Conference Board of the Mathematical Sciences [CBMS]. (2001). *The mathematical education of teachers* (Vol. 11). Providence, Rhode Island: American Mathematical Society.

Connelly, F. M., & Clandinin, D. J. (1986). On narrative method, biography and narrative unites in the study of teaching. Retrieved from ERIC database. (ED277664)

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, *44*(4), 613-642. Retrieved from http://search.ebscohost.com

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage Publications.

Cuenca, A. (2011). The role of legitimacy in student teaching: Learning to "feel" like a teacher. *Teacher Education Quarterly*, *38*(2), 117-130. Retrieved from http://search.ebscohost.com

Daehler, K. R., & Shinohara, M. (2001). A complete circuit is a complete circle: Exploring the potential of case materials and methods to develop teachers' content knowledge and pedagogical content knowledge of science. *Research in Science Education*, *31*(2), 267-288. Retrieved from http://search.ebscohost.com

Dana, N. F. (1992, February). *Towards preparing the monocultural teacher for the multicultural classroom*. Paper presented at the Annual Meeting of the Association of Teacher Educators, Orlando, FL. Retrieved from http://www.eric.ed.gov

Dana, T. M., Campbell, L. M., & Lunetta, V. N. (1997). Theoretical bases for reform of science teacher education. *The Elementary School Journal*, *97*(4), 419-432. Retrieved from http://search.ebscohost.com

Davis, E., & Petish, D. (2005). Real-world applications and instructional representations among prospective elementary science teachers. *Journal of Science Teacher Education*, *16*(4), 263-286. doi:10.1007/s10972-005-8892-4

Dawkins, K. R., Dickerson, D. L., McKinney, S. E., & Butler, S. (2008). Teaching density to middle school students: Preservice science teachers' content knowledge and pedagogical practices. *The Clearing House*, *82*(1), 21-26. Retrieved from http://search.ebscohost.com

Denzin, N. K., & Lincoln, Y. S. (2003). Introduction: The discipline and practice of qualitative research. In N.K. Denzin & Y. S. Lincoln (Eds.), *The Landscape of Qualitative Research: Theories and Issues*, (2nd ed.), (pp.1-46), Thousand Oaks, CA: Sage Publications.

Denzin, N. K., & Lincoln, Y. S. (2005). Introduction: The discipline and practice of qualitative research. In N.K. Denzin & Y. S. Lincoln (Eds.), *The Sage Handbook of Qualitative Research*, (3rd ed.), (pp. 1-32). Thousand Oaks, CA: Sage Publications.

De Villiers, M. (2004), Using dynamic geometry to expand mathematics teachers' understanding of proof. *International Journal of Mathematics Education Science and Technology, 35*(5), 703-724. Retrieved from http://search.ebscohost.com

Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educative process*. Boston, MA: Heath and Co.

EDC Science Education. (2003). *Insights.* Dubuque, IA: Kendall/ Hunt Publishing.

Ergin, I., Kanli, U., & Unsal, Y. (2008). An example for the effect of 5E model on the academic success and attitude levels of students': "Inclined projectile motion". *Turkish Science Education*, *5*(3), 47-59. Retrieved from http://search.ebscohost.com

Emenaker, C. (1996). A problem-solving based mathematics course and elementary teachers' beliefs. *School Science and Mathematics*, *96*(2), 75-84.

Even, R., Tirosh, D., & Markovits, Z. (1996, July). *Teacher subject matter knowledge and pedagogical content knowledge: Research and development.* Paper presented at the International Group for the Psychology of Mathematics Education, Valencia, Spain (pp. 150-165). Retrieved from http://www.eric.ed.gov

Feiman-Nemser, S., & Buchmann, M. (1986). *Knowing, thinking and doing in learning to teach: A research framework and some initial results. Research Series No. 180*. Retrieved from ERIC database. (ED274653)

Fennell, H. A. (1993). *Student teachers' evaluation of their preparation for internship course: A case study.* Retrieved from ERIC database. (ED361335)

Freeman, C. C., & Smith, D. L (1997, March). *Active and Engaged? Lessons from an Interdisciplinary and Collaborative College Mathematics and Science Course for Preservice Teachers*. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL. Retrieved from ERIC database. (ED411210)

Frykholm, J., & Glassen, G. (2005). Connecting science and mathematics instruction: Pedagogical context knowledge for teachers. *School Science and Mathematics, 105*(3), 127-141.

Fuller, R. A. (1996, October). *Elementary teachers' pedagogical content knowledge of mathematics*. Paper presented at the Mid-Western Educational Research Association Conference, Chicago, Il. Retrieved from ERIC database. (ED401270)

Fulp, S. L. (2002). *2000 National survey of science and mathematics education: Status of elementary school science teaching*. Chapel Hill, NC: Horizon Research, Inc.

Garber, S. (2007). *Sputnik and the dawn of the Space-Age*. Retrieved from http://history.nasa.gov/sputnik

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. New York, NY: Basic Books.

Gates, B. (2005). *Prepared remarks for the National Summit on High schools*. Retrievedfrom:http://www.gatesfoundation.org/FileReturn.aspx?column=Speech_Transcript_CMS&headerkey=Speech&page=%2fspeeches-commentary%2fPages%2fbill-gates-2005-national-education-summit.aspx&name=speech.html&returntype=htmlfile.

Gee, C. J., Boberg, W. S., & Gabel, D. L. (1996, April). *Preservice elementary teachers: Their science content knowledge, pedagogical knowledge, and pedagogical content knowledge*.

Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, St. Louis, MO. Retrieved from ERIC database. (ED393702)

Gitomer, D. H. (2007). *Teacher quality in a changing policy landscape: Improvements in the teacher pool.* (Policy Information Report). Retrieved from Educational Testing Service website: http://www.ets.org/ Meda/ Education_ Topics/pdf/TQ_full_report.pdf

Glaser. B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Piscataway, NJ: Aldine Transaction.

Green, M., Piel, J. A., & Flowers, C. (2008). Reversing education majors' arithmetic misconceptions with short term instruction using manipulatives. *The Journal of Educational Research*, *10*(4), 234-242. Retrieved from http://www.eric.ed.gov

Gresham, G. (2007). A study of mathematics anxiety in pre-service teachers. *Early Childhood Education Journal*, *35*(2), 181-188. doi:10.1007/s10643-007-0174-7

Goodnough, K., & Nolan, B. (2008). Engaging elementary teachers' pedagogical content knowledge: Adopting problem-based learning in the context of science teaching and learning. *Canadian Journal of Science, Mathematics & Technology Education*, *8*(3), 197-216. doi:10.1080/14926150802315130

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. W. (2009). Teaching practice-A cross-professional prospective. *Teachers College Record*, 111(9), 2055-2100. Retrieved from http://search.ebscohost.com

Gyllenpalm, J., Wickman, P-O., & Holmgren, S-O. (2010). Teachers' language on scientific inquiry: Methods of teaching or methods of inquiry? *International Journal of Science Education*, *32*(9), 1151-1172. Retrieved from http://search.ebscohost.com/

Haefner L. A., & Zembal-Saul, C. (2004). Learning by doing? Prospective elementary teachers' developing understanding of scientific inquiry and science teaching and learning. *International Journal of Science Education*, *26*(13), 1653-1674. Retrieved from http://search.ebscohost.com

Hampton, B., Odom, A. L, & Settlage, J.Jr.. (1995, April). *The development and application of a diagnostic test to assess teachers' understanding of the learning cycle*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, San Francisco, CA. Retrieved from ERIC database. (ED387333)

Hancock, E. S., & Gallard, A. J. (2004). Preservice Science Teachers' Beliefs about Teaching and Learning: The Influence of K-12 Field Experiences. *Journal of Science Teacher Education*, *15*(4), 281-291. Retrieved from http://search.ebscohost.com

Hanuscin, D. L., & Lee, M. H. (2008). Using the Learning Cycle as a Model for Teaching the Learning Cycle to Preservice Elementary Teachers. *Journal of Elementary Science Education*, *20*(2), 51-66. Retrieved from http://www.eric.ed.gov/

Hargreaves, A. (1984). Experience counts, theory doesn't: How teachers talk about their work. *Sociology of Education*, *57*(4), 244-254. Retrieved from http://search.ebscohost.com

Harkness, S., D'ambrosio, B., & Morrone, A. (2007, June). Preservice elementary teachers' voices describe how their teacher motivated them to do mathematics. *Educational Studies in Mathematics, 65*(2), 235-254. Retrieved January 24, 2009, doi:10.1007/s10649-006-9045-1.

Harlow, D. B., & Otero, V. K. (2006). Beyond concepts: Transfer from inquiry-based physics to elementary classrooms. *AIP Conference Proceedings, 883*(1), 73-76. Retrieved from http://www.eric.ed.gov

Hatch, J. A. (2002). *Doing qualitative research in education settings*. Albany, NY: State University of New York Press.

Hatton, M. (2008). *Preservice elementary teachers' concerns about teaching science*. Retrieved from ERIC database. (ED503450)

Heywood, D. S. (2007). Problematizing science subject matter knowledge as a legitimate enterprise in primary teacher education. *Cambridge Journal of Education, 37*(4), 519-542. doi:10.1080/03057640701705856

Hill, L. (1997). Just tell us the rule: Learning to teach elementary mathematics. *Journal of Teacher Education*. *48*(3), 211-222. Retrieved from http://search.ebscohost.com

Hill, H., & Ball, D. L. (2009). The curious - - and crucial case - - of mathematical knowledge for teaching. *Phi Delta Kappan, 91*(2), 68-71. Retrieved from http://www.eric.ed.gov

Hill, H. C., Blunk, M., Charalambous, C., Lewis, J., Phelps, G. C., Sleep, L., & Ball, D. L. (2008). Mathematical knowledge for teaching and the mathematical quality of instruction: An exploratory study. *Cognition & Instruction, 26*(4), 430-511. Retrieved from http://search.ebscohost.com

Hoffer, A. R. (1993). The excitement of learning with our students: An escalator of mathematical knowledge. *The Mathematics Teacher*, *86*(4), 315-319.

Hovey, A., Hazelwood, C., & Svedkauskite, A. (2005). *Critical issue: Science education in the era of No child left behind*. http:// www.ncrel.org/sdrs/ areas/issues/content/cntareas/ science/sc600.pdf

Howitt, C. (2007). Pre-service elementary teachers' perceptions of factors in an holistic methods course influencing their confidence ion teaching science. *Research in Science Education*, *37*(1), 41-58.

Huang, H-M. E. (2000, August). *Investigating of teachers' mathematical conceptions and pedagogical content knowledge in mathematics*. Paper presented at the Working Group for Action Mathematics Education in Pre and Primary School, Makuhari, Japan. Retrieved from http://www.nku .edu/~sheffield/edithpbyd3.html

Illinois Central College. (1979). *DOORS Project: Development of operational reasoning skills.* Retrieved from ERIC database. (ED203775)

Interstate Teacher Assessment and Support Consortium [INTASC] (n.d.). *The INTASC standards*. Retrieved from http://www.wresa.org/Pbl/ The%20INTASC% 20 Standards%20overheads.htm

Jacobs, J. E., & Paris, S. G. (1987). Children's metacognition about reading: Issues in definition, measurement, and instruction. *Educational Psychologist, 22*(2 &3), 255-278. Retrieved from http://search.ebscohost.com

Jaeger, M., & Lauritzen, C. (1992, November). *The construction of meaning from experience*. Paper presented at the Annual Meeting of the National Council of Teachers of English, Louisville, KY. Retrieved from ERIC database. (ED358410)

Johnson, W. N. (1980). *Perception changes of students studied in a field-centered methods course for teachers of elementary school mathematics and upon completion of student teaching: A follow-up study*. Retrieved from ERIC database. (ED187545)

Jones, K. (2000, November). Teacher knowledge and professional development in geometry. In T. Rowland (Ed.). *Proceedings of the British Society for Research into Learning Mathematics, 20*(3), 109-114.

Jong, O. D., & Brinkman, F. (1999). Investigating student teachers' conceptions of how to teach: International network studies from science and mathematics education. *European Journal of Teacher Education*, *22*(1), 5-9. Retrieved from http://search.ebscohost.com

Jurdak, M., & Shahin, I. (2001). Problem solving activity in the workplace and the school: The case of constructing solids. *Educational Studies in Mathematics*, *47*(3), 297-315. Retrieved from http://www.search.ebscohost.com

Justi, R., & Gilbert, J. (2000). History and philosophy of science through models: Some challenges in the case of the 'atom'. *International Journal of Science Education*, *22*(9), 993-1009. Retrieved from http://search.ebscohost.com

Justi, R., & van Driel, J. (2005). The development of science teachers' knowledge on models and modeling: promoting, characterizing, and understanding the process. *International Journal of Science Education*, *27*(5), 549-573. Retrieved from http://search .ebscohost.com

Kadlec, A., & Friedman, W. (2007). Important, but not for me: Parents and students in Kansas and Missouri talk about math, science, and technology education. A Report from Public Agenda. *Public Agenda*, Retrieved from http://www.publicagenda.org/files/pdf/ important_but_not_for_me.pdf

Ka-Ming, Y., & Kit-Tai, H. (2006). Constructivist teaching and teacher-centred teaching: A comparison of students' learning in a university course. *Innovations in Education & Teaching International*, *43*(3), 279-290. doi:10.1080/14703290600750861

Karplus, R. (1976, April). *Science Teaching and the development of reasoning. Occasional Paper Series*. Paper presented at the Annual Meeting of the National Association for

Research in Science Teaching, San Francisco, CA. Retrieved from ERIC database. (ED123128)

Kelly, J. (2000). Rethinking the elementary science methods course: A case for content, pedagogy, and informal science education. *International Journal of Science Education, 22*(7), 755-777. Retrieved from http://search.ebscohost.com

Kim, B., & Darling, L. (2009). Monet, Malaguzzi, and the constructive conversations of preschoolers in a Reggio-Inspired classroom. *Early Childhood Education Journal*, *37*(2), 137-145. doi:10.1007/s10643-009-0323-2

Kind, K. K. (1999). *Dialogue on early childhood science, mathematics, and technology education: First experiences in science, mathematics, and technology*. Retrieved from http://www.project2061.org/publications/earlychild/online/experience/ lind.htm

Kistler, B. (1997, November). *Mathematics Courses for the Prospective Teacher*. Paper presented at the Annual Conference of the American Mathematical Association of Two-Year Colleges, Atlanta, GA. Retrieved from ERIC database. (ED418926)

Klein, D. (2003). *A brief history of American K-12 mathematics education in the 20th Century*. Retrieved from http://www.csun.edu/~vcmth00m/AHistory.html

Kratochvil, D. W., & Crawford, J. J. (1971). *Science curriculum improvement study developed by the Science Curriculum Improvement Project*. (AIR-21900-11-71-TR-4). Washington, D.C.: Office of Program Planning and Evaluation. (ED058102).

Ksiazek, K., Mcglathery, K., Reynolds, L., Schwarzschild, A., Wilkerson, C., Carruthers, T….Murray, L. (2009). Learning about coastal trends: What is the story with seagrass… and how does it affect me? *Science Activities*, *46*(3), 27-31. Retrieved from http://search.ebscohost.com

Lancy, D. F. (1993). *Qualitative research in education: An introduction to the major traditions*. White Plains, NY: Longman Publishing Group.

Lawrence Hall of Science. (2003). *Full option science system* (FOSS). Nashua, NH: Delta Education.

Lawson, A. E., Abraham, M. R., & Renner, J. W. (1989). *A theory of instruction: Using the learning cycle to teach science concepts and thinking skills*. Retrieved from http://www.eric.ed.gov

Leitzel, J. R. C. (Ed.). (1991). *A call for change: Recommendations for the mathematical preparation of teachers of mathematics / Committee on the Mathematical Education of Teachers.* Washington, DC: Mathematical Association of America.

Leonard, J., Boakes, N., & Moore, C. M. (2009). Conducting Science Inquiry in Primary Classrooms: Case Studies of Two Preservice Teachers' Inquiry-Based Practices. *Journal of Elementary Science Education, 21*(1), 27-50. Retrieved from http://search.ebscohost. com

Lever-Duffy, J., & MacDonald, J. B. (2010). *Teaching and learning with technology* (4th ed). Upper Saddle River, N.J.: Pearson.

Li, Y., & Fuson, K. (2002). Curriculum materials and its uses in teaching and learning mathematics. *Proceedings of the Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 99-103). Columbus, OH: ERIC/CSMEE Publications. Retrieved from ERIC database. (ED471753)

Lindgren, J., & Bleicher, R. E. (2005). Learning the learning cycle: The differential effect on elementary preservice teachers. *School Science and Mathematics, 105*(2), 61-72.

Liu, T.-C., Peng, H., Wu, W.-H., & Lin, M.-S. (2009). The effects of mobile natural-science learning based on the 5E learning cycle: A case study. *Educational Technology & Society, 12* (4), 344-358. Retrieved from http://search.ebscohost.com

Lloyd, G. M., & Frykholm, J. A. (2000). How innovative middle school mathematics can change prospective elementary teachers' conceptions. *Education*, *120*(3), 575-580.

Lonning, R. A., & DeFranco, T. C. (1994). Development and integration of an integrated mathematics/science preservice elementary methods course. *School Science and Mathematics, 94*(1), 18-25.

Lonning, R. A., DeFranco, T. C., & Weinland, T. P. (1998). Development of theme-based, interdisciplinary integrated curriculum: A theoretical model. *School Science and Mathematics, 98*(6), 312-318.

Lubinski, C. A., Otto, A. D., Rich, B. S., & Jaberg, P. A. (1995, October). *Content knowledge, beliefs, and practices: A comparison among six preservice teachers*. Paper presented at the Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education, Columbus, OH. Retrieved from ERIC database. (ED389600)

Manouchehri, A. (1997). School mathematics reform: Implications for mathematics teacher preparation. *Journal of Teacher Education*, *48*(3), 197-210. Retrieved from http://search.ebscohost.com

Marek, E. A. (2008). Why the learning cycle? *Journal of Elementary Science Education, 20*(3), 63-69.Retrieved from http://search.ebscohost.com

Marek, E. A., & Cavallo, A. M. (1997). *The learning cycle: Elementary school science and beyond.* Portsmouth, NH: Heinemann.

Marek, E. A., Laubach, T. A., & Pedersen, J. (2003). Preservice elementary school teachers' understandings of theory based science education. *Journal of Science Teacher Education, 14*(3), 147-159. Retrieved from http://search.ebscohost.com

Marek, E. A., Maier, S. J., & McCann, F. (2008). Assessing understanding of the learning cycle: The ULC. *Journal of Science Teacher Education*, *19*(4), 375-389. Retrieved from http://search.ebscohost.com

Marshall, C., & Rossman, G. B. (1995). *Designing qualitative research* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Martin, T., McCrone, S., Bower, M., & Dindyal, J. (2005). The interplay of teacher and student actions in the teaching and learning of geometric proof. *Educational Studies in Mathematics*, *60*(1), 95-124. doi:10.1007/s10649-005-6698-0

Matthews, M. E., & Seaman, W. I. (2007). The effects of different undergraduate mathematics courses on the content knowledge and attitude towards mathematics of preservice elementary teachers. *Issues in the Undergraduate Mathematics Preparation of Teachers*, Vol1. Retrieved from http://www.eric.ed.gov

McGinnis, J., Kramer, S., & Watanabe, T. (1998, April). *A longitudinal assessment of teacher candidates' attitudes and beliefs in a reform-based mathematics and science teacher preparation program*. Paper presented at the Annual Meeting of the National Association of Research in Science Teaching, San Diego, CA. Retrieved from ERIC database. (ED421348)

McGinnis, J., & Parker, C. (1999, March). *Teacher candidates' attitudes and beliefs of subject matter and pedagogy measured throughout their reform-based mathematics and science teacher preparation program*. Paper presented at the Annual Meeting of the National

Association of Research in Science Teaching, Boston, MA. Retrieved from ERIC database. (ED 429830)

McLeod, K., & Huinker, D. (2007). University of Wisconsin-Milwaukee mathematics focus courses: Mathematics content for elementary and middle grades teachers. *International Journal of Mathematical Education in Science Teaching*, *38*(7), 949-962. doi:10.1080/00207390701579498

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco, CA: Wiley & Sons.

Molina, D., Hull, S., Schielack, J., & Education, T. (1997). *Guidelines for the Mathematical Preparation of Prospective Elementary Teachers*. Retrieved from ERIC database. (ED 436370)

Monhardt, L. (2009). "Is a bird an animal?" The necessity of science content knowledge. *Journal of College Science Teaching, 38*(4), 8-10. Retrieved from http://search.ebscohost.com

Morrison, J. (2008). Individual inquiry investigation in an elementary science methods course. *Journal of Science Teacher Education*, *19*(2), 117-134.

National Commission on Excellence in Education [NCEE]. (1983). *A nation at risk: The importance of educational reform*. Retrieved from http:www.ed.gov/pubs/ NatAtRisk/index.html

National Council for Accreditation of Teacher Education [NCATE]. (2010, November). *Transforming teacher education through clinical practice: A national strategy to prepare effective teachers (Report of the Blue Ribbon Panel on clinical preparation and* *partnerships for improved student learning).* Retrieved from NCATE website: http://www.ncate.org/LinkClick.aspx?fileticket=zzeiB1OoqPk%3d&tabid=715.

National Council of Teachers of Mathematics [NCTM]. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (1991). *Professional standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (1995). *Assessment standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (2006). *Curriculum focal points for prekindergarten through grade 8 mathematics: A quest for coherence*. Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (2009). *Focus in high school mathematics: Reasoning and sense-making*. Reston, VA: Author.

National Research Council [NRC]. (1989). *Everybody Counts. A report to the nation on the future of mathematics education.* Washington, DC: National Academy Press.

National Research Council [NRC]. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council [NRC], (2001). *Adding it up: Helping children learn mathematics*. Mathematics Learning Study Committee, J. Kilparic, J. Swaford and J. Findell (Eds). Washington DC: National Academy Press.

National Science Board [NSB] (2004, January). *An emerging and critical problem of the science and engineering labor force: A companion to Science and Engineering Indicators 2004*. Retrieved from http://www.nsf.gov/statistics/nsb0407/

National Science Foundation [NSF]. (2009). *A timeline of NSF history*. Retrieved from http://www.nsf.gov/about/history/overview-50.jsp

National Science Resources Center. (2003). *Science technology for children*. Burlington, N.C.: Carolina Biological Supply Co.

National Science Teachers Association. (2003). *Standards for science teacher preparation*. Retrieved from http://www.nsta.org/pdfs/NSTAstandards2003.pdf

Neal., L. A. (1962). Method of scientific literacy. *The Science Teacher*, *29*(5), 53-55.

Newton, D. P., & Newton, L. D. (2001). Subject content knowledge and teacher talk in the primary science classroom. *European Journal of Teacher Education*, 24(3), 369-379. Retrieved from http://search.ebscohost.com/

No Child Left Behind (NCLB) Act of 2001, Pub. L. No. 107-110, § 115, Stat.1425 (2002).

Noori, K. K. (1994). *A constructivist/reflective paradigm: A model for the early childhood program at Tuskegee University*. Retrieved from ERIC database. (ED370888)

Odom, A. L., & Settlage, J. (1996). Teachers' understandings of the learning cycle as assessed with a two-tier test. *Journal of Science Teacher Education*, *7*(2), 123-142.

Offer, J., & Mireles, S. V. (2009, March). Mix it up: Teachers' beliefs on mixing mathematics and science. *School Science and Mathematics, 109*(3), 146-152.

Olgun, O. S. (2009). Engaging elementary preservice teachers with active learning teaching methodologies. *The Teacher Educator*, *44*(2), 113-125. Retrieved from http://search.ebscohost.com

Oliver-Hoyo, M., & Allen, D. (2006). The use of triangulation methods in qualitative educational research. *Journal of College Science Teaching*, *35*(4), 42-47. Retrieved from http://search.ebscohost.com

Ören, F., & Tezcan, R. (2009). The effectiveness of the learning cycle approach on learners' attitude toward science in seventh grade science classes of elementary school (English). *Ilkogretim Online*, *8*(1), 103-118. Retrieved from http://search.ebscohost.com

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, *62*(3), 307-332.

Park Rogers, M. A., & Abell, S. K. (2008). The design, enactment, and experience of inquiry-based instruction in undergraduate science education: a case study. *Science Education*, *92*(4), 591-607. Retrieved from http://search.ebscohost.com

Partnership for 21st Century Skills (2006). *Most young people entering the U.S. workforce lack critical skills essential for success*. Retrieved from http://www.p21.org/index.php?option=com_content&task=view&id=250

Partnership for 21st Century Skills (2009). *P21 Framework definitions document*. Retrieved from http://www.p21.org/documents/P21_Framework_Definitions.pdf

Paton, B. A., Fry, J., & Klages, C. (2008). Teacher candidates and master math teachers personal concepts about teaching mathematics. *Education*, *128*(3), 486-497.

Patton, M.Q. (2002). *Qualitative research & evaluation methods*. (3rd ed). Thousand Oaks, CA: Sage Publications.

Pearson Education (2007). *Investigations in number data and space*. Glenview, Ill: Scott Foresman.

Pehkonen, E. (2001). A hidden regulating factor in mathematics classrooms: mathematics-related beliefs. In M. Ahtee, O. Bjorkqvist, Pehkonen, E., & V. Vatanen (Eds.), *Research in mathematics and science education: From beliefs to cognition, from problem solving to understanding*,11-36.

Philipp, R. A., Thanheiser, E., Clement, L. (2002). The role of children's mathematical thinking experience in the preparation of prospective elementary school teachers. *International Journal of Educational Research, 37*(2), 195-210. Retrieved from http://search.ebscohost.com

Philippou, G., Charalambos, C., & Leonidas, K. (2003). The development of student teachers' efficacy beliefs in mathematics during practicum. In *Proceedings of the 27th International Group for the Psychology of Mathematics Education Conference Held Jointly with the 25th PME-NA Conference (Honolulu, HI, July). Vol. 4*, p.7 -14. N. International Group for the Psychology of Mathematics Education. Retrieved from http://search.ebscohost.com

Piaget, J. (1976). *Piaget sampler: An introduction to Jean Piaget through his own words*. S.F. Cambell (ed). New York, NY: Wiley.

Plonczak, I. (2010). Videoconferencing in math and science preservice elementary teachers' field placements. *Journal of Science Teacher Education*, *21*(2), 241-254. Retrieved from http://search.ebscohost.com

Poole, M. (1995). *Beliefs and values in science education. Developing science and technology education*. Bristol, PA: Open University Press. Retrieved from http://www.eric.ed.gov. (ED390648)

Posner, G. J., & Gertzog, W. A. (1982). The clinical interview and the measurement of conceptual change. *Science Education*, *66*(2), 195-210.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Putman, S. M. (2009). Grappling with classroom management: The orientations of preservice teachers and impact of student teaching. *The Teacher Educator*, *44*(4), 232-247. Retrieved from http://search.ebscohost.com

Quinn, R. J. (1997). Effects of mathematics methods courses on the mathematical attitudes and content knowledge of preservice teachers. *The Journal of Educational Research*, *91*(2), 108. Retrieved from http://search.ebscohost.com

Renner, J. W., & Lawson, A. E. (1973). Piagetian theory and instruction in physics. *The Physics Teacher*, *11*(3), 165-169.

Renner, J. W., Abraham, M. R., Grzybowski, E. B., & Marek, E. (1990). Understandings and misunderstandings of eighth graders of four physics concepts found in textbooks. *Journal of Research in Science Teaching, 27*(1), 35-54.

Repman, J., Zinskie, C., & Carlson, R. (2005). Effective use of CMC tools in interactive online learning. *Computers in the Schools*, *22*(1/2), 57-69. doi:10.1300/J025v22n01A.06

Reynolds, A., & Elias, P. (1991). *What is good teaching? A review of the literature*. Princeton, NJ: Educational Testing Service.

Reys, R. E., Lindquist, M. M., Lambdin, D. V., Suydam, M. N., & Smith, N. L. (2003). *Helping children learn mathematics*. (6th ed.). Hoboken, NJ: Wiley & Sons.

Rice, D. (2005). I didn't know oxygen could boil! What preservice and inservice elementary teachers' answers to 'simple' science questions reveals about their subject matter knowledge. *International Journal of Science Education*, *27*(9), 1059-1082. doi:10.1080/09500690500069426.

Richards, J., Levin, D. M., & Hammer, D. (2011, April). *Supporting preservice teachers' reform based practices: The importance of intellectual and emotional support in a community*. Paper presented at the Annual Meeting of American Educational Research Association, New Orleans, LA. Retrieved from ERIC database. (ED520061)

Saldana, J. (2009). *The coding manual for qualitative researchers*. Thousand Oaks, CA: Sage Publications.

Sambs, H. (1991, April). *Problem solving in physics and mathematics-What do they have in common? (Creating a base for research and teaching).* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Lake Geneva, WI. Retrieved from ERIC database. (ED335222)

Sanger, M. J. (2006). Is inquiry-based instruction good for elementary teaching majors? The effects on chemistry content knowledge and views about teaching and learning science. *AIP Conference Proceedings*, *883*(1), 7-10. doi: 10.1063/1.2508677

Schlenker, R. M., Blanke, R., & Mecca, P. (2007). Using the 5E learning cycle sequence with carbon dioxide. *Scientific Activities*, *44*(3), 83-93. Retrieved from http://search. ebscohost.com

Schmidt, L. (2008). How we don't learn. *Leadership*, *38*(2), 10-14. Retrieved from http://search. ebscohost.com

Schmidt, W. H., Tatto, M. T., Bankov, K., Blomke, S., Cedillio, T., Cogan, L., … Schwille, J. (2007). *The preparation gap: Teacher education for middle school mathematics in six countries* (MT21 Report). MSU Center for Research in Mathematics and Science Education. Retrieved from http://usteds.msu/MT21Report.pdf

Scott, D. (2007). Resolving the quantitative–qualitative dilemma: a critical realist approach. *International Journal of Research & Method in Education*, *30*(1), 3-17. doi:10.1080/17437270701207694

Securro, S. Jr. (1994). *Perceived impact of the "Ecology of Student Teaching"*. Retrieved from ERIC database. (ED374100)

Senk, S. L., Keller, B., & Ferrini-Mundy, J. (Eds.). (2000). *Teacher preparation: K-12 mathematics*. Retrieved from Mathematical Association of America website: http://www.maa.org/cupm/crafty/Chapt15.pdf

Settlage, J. (2000). Understanding the learning cycle: Influences on abilities to embrace the approach by preservice elementary school teachers. *Science Education*, *84*(1), 43-50. Retrieved from http://www.eric.ed.gov

Shapiro, S. (1983). Mathematics and reality. *Philosophy of Science*, *50*(4), 523-548. Retrieved from EDS Foundation Index.

Shaw, E. R., & Cronin-Jones, L. (1989). *Influence of methods instruction on pre-service elementary and secondary science teachers' beliefs*. Retrieved from ERIC database. (ED318639)

Shulman, L. (1986). Those who understand knowledge growth in teaching. *Educational Researcher*, *15*(2), 4-14.

Simon, M. A. (1992, April). *Learning mathematics and learning to teach: Learning cycles in mathematics education.* Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA. Retrieved from ERIC database. (ED349174)

Skemp, R. R. (1976). Relational understanding and instrumental understanding. *Mathematics Teaching*, 7, 20-26.

Smith, D. J., & Sanche, R. P. (1993). Interns' personally expressed concerns: A need to extend the Fuller Model? *Action in Teacher Education*, *15*(1), 36-41. Retrieved from http://search.ebscohost.com

Soomor, A. Q., Qaisrani, M. N., Rawat, K. J., & Mughal, S. H. (2010). Teaching physics through learning cycle model: An experimental study. *Journal of Educational Research*, *13*(2), 5-18.

Spears, R., Postmes, T., Lea, M., & Wolbert, A. (2002). When are net effects gross products? *Communication Journal of Social Issues*, *58*(1), 91. Retrieved from http://search. ebscohost.com

Spielman, L. J., & Lloyd, G. M. (2004). The impact of enacted mathematics curriculum models on prospective elementary teachers' course perceptions and beliefs. *School Science and Mathematics*, *104*(1), 32-44.

Sriraman, B., & Lesh, R. (2007). A conversation with Zoltan P. Dienes. *Mathematical Thinking and Learning*, *9*(1), 59-75.

Stamp, N., & O'Brien, T. (2005). GK-12 Partnership: A model to advance change in science education. *Bioscience*, *55*(1), 70-77. Retrieved from http://search.ebscohost.com

Stake, R. E. (2005). Qualitative case studies. In N.K. Denzin & Y. S. Lincoln (Eds.), *The Sage Handbook of Qualitative Research* (3rd ed.). (pp. 433-466). Thousand Oaks, CA: Sage Publications.

Steen, L. A. (1990). *Science and mathematics education: Similarities and differences*. Retrieved from http://www.stolaf.edu/people/steen/Papers/similarities.html

Stinson, K., Harkness, S. S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration?: Models and characterization. *School Science and Mathematics*, *109*(3), 153-161.

Stotsky, S. (2006). Who should be accountable for what beginning teachers need to know? *Journal of Teacher Education*, *57*(3), 256-268.

Stuessy, C. L. (1993). Concept to application: Development of an integrated mathematics/science methods course for preservice elementary teachers. *School Science and Mathematics, 93*(2), 55-62.

Stuessy, C. L., & Naizer, G. L. (1996). Reflection and problem solving: Integrating methods of teaching mathematics and science. *School Science and Mathematics, 96*(4), 170-177.

Summers, M., Kruger, C., & Childs, A. (2001). Understanding the science of environmental issues: development of a subject knowledge guide for primary teacher education. *International Journal of Science Education*, *23*(1), 33-53. Retrieved from http://search.ebscohost.com

Swartz, R. (1982). Alternative learning strategies as part of the educational process. *Science Education, 66*(2), 269-279.

Tal, R. T., Dori, Y. J., Keiny, S., & Zoller, U. (2001). Assessing conceptual change of teachers involved in STES education and curriculum development: The STEMS project approach.

International Journal of Science Education, 23(3), 247-262. Retrieved from http://search.ebscohost.com

Taylor, C. (2009). *The effects of a combined mathematics content/methods course involving Learning Cycles on preservice elementary teachers' beliefs about the nature, teaching and learning of mathematics*. Ed.D. dissertation, Temple University, United States-Pennsylvania. Retrieved from Dissertations & Thesis: A&I. (Publication No. AAT 3344406).

Tosun, T. (2000). The beliefs of preservice elementary teachers toward science and science teaching. *School Science and Mathematics*, *100*(7), 374. Retrieved from http://search.ebscohost.com

Tracy, D. M. (1999). SSMiles. *School Science and Mathematics*, *99*(7), 400-408.

Tracy, D. M. (2003). Linking math, science, and inquiry-based learning: An example from a mini-unit on volume. *School Science and Mathematics*, *103*(4), 400-413.

Tracy, D. M., Follo, E. J., Gibson, S. L., & Eckart, J. A. (1998). *Success after failure: A case study of three teacher interns*. Retrieved from ERIC database. (ED425134)

Trujillo, K., & Hadfield, O. (1999, June). Tracing the roots of mathematics anxiety through in-depth interviews with preservice elementary teachers. *College Student Journal*, *33*(2), 219. Retrieved from http://search.ebscohost.com

Turnuklu, E. B., & Yesildere, S. (2007). The pedagogical content knowledge in mathematics: pre-service primary mathematics teachers' perspectives in Turkey. *JUMPST: The Journal*, *1*, 1-13.

Urey, M., & Calik, M. (2008). Combining different conceptual change methods within 5E model: A sample teaching design of 'cell' concepts and its organelles. *Asia-Pacific*

Forum on Science Learning and Teaching, *9*(2), 1-15. Retrieved from http://www.eric.ed.gov

U.S. Department of Education. (1991). *America 2000: An education strategy* (GPO NO:ED 0591-13). Washington, DC: Author.

U.S. Department of Education. (2011). *Math teachers: The nation builders of the 21st Century: Remarks to the National Council of Teachers of Mathematics*. Retrieved from http://www.ed.gov/news/speeches/math-teachers-nation-builders-21st-century

van Es, E. A., & Conroy, J. (2009). Using the Performance Assessment for California Teachers to Examine Pre-Service Teachers' Conceptions of Teaching Mathematics for Understanding. *Issues in Teacher Education*, *18*(1), 83-102. Retrieved from http://www.eric.ed.gov

Veal, W. R. (2004). Beliefs and knowledge in chemistry teacher development. *International Journal of Science Education*, *26*(3), 329-351. Retrieved from http://www.eric.ed.gov

Vernette, D., Foote, D., Bird, C., Mesibov, D., Harris-Ewing, D., & Battaglia, D. (2001). Understanding Constructivism(s): A primer for parents and school board members. *Education*, *122*(1), 87. Retrieved from http://search.ebscohost.com

Vygostsky, L. S. (1962). *Thought and language. Edited and translated by Eugenia Hanfmann and Gertrude Vakar*. Cambridge, MA: MIT Press.

Walker, C. L., McGill, M. T., Buikema, A. L., & Stevens, A. M. (2008). Implementing inquiry-based learning in teaching serial dilutions. *Journal of College Science Teaching*, *37*(6), 56-61. Retrieved from http://www.eric.ed.gov

Wang, J.-R., Kao, H.-L., & Lin, S.-W. (2010). Preservice teachers' initial conceptions about assessment of science learning: The coherence with their views of learning science. *Teaching and Teacher Education*, *26*, 522-529.

Waters-Adams, S. (2006). The relationship between understanding of the nature of science and practice: The influence of teachers' beliefs about education, teaching and learning. *International Journal of Science Education*, *28*(8), 919-944. doi:10.1080/09500690500498351

Weiss, I. R. (1994). *A Profile of Science and Mathematics Education in the United States:1993*. Chapel Hill, NC: Horizon Research. Retrieved from ERIC database. (ED382461)

Weld, J., & Funk, L. (2005). "I'm not the science type": Effect of an inquiry biology content course on preservice elementary teachers' intentions about teaching science. *Journal of Science Teacher Education*, *16*(3), 189-204. Retrieved from http://www.search.ebscohost.com

Wiegel, H., & Bell, K. (1996). *Preservice elementary teachers' affective responses to computer activities in mathematics content courses*. Retrieved from ERIC database. (ED409180)

Wilcox, S., Schram, P., Lappan, G., & Lanier, P. (1991). *The role of learning community in changing preservice teachers' knowledge and beliefs about mathematics education.* East Lansing, MI: National Center for Research on Teacher Education. (ED330680)

Williams, S. R., & Baxter, J. A. (1996). Dilemmas of discourse-oriented teaching in one middle school mathematics classroom. *The Elementary School Journal*, *97*(1), 21-38.

Withee, T., & Lindell, R. (2006). Different views on inquiry: a survey of science and mathematics methods instructors. *AIP Conference Proceedings, 818*(1), 125-128. doi: 10.1063/1.2177039

Wong, K. K., Guthrie, J. W., & Harris, D. N. (2003). A nation at risk: A 20 year reappraisal. *Peabody Journal of Education*, v 79. Boca Raton, Fl: Taylor and Frances Group.

Woodruff, E., & Meyer, K. (1997). Explanations from intra- and inter-group discourse: Students building knowledge in the science classroom. *Research in Science Education*, *27*(1), 25-39.

Yin, R. K. (2009). *Case study research: Design and methods*. (4th ed.). Thousand Oaks, CA: Sage Publications.

Yore, L. D. (1997, November). *Leadership interns in undergraduate elementary school science education programs.* Paper presented at the Annual Meeting of School Science and Mathematics Association, Miwaukee, WI. Retrieved from ERIC database. (ED414199)

Zambo, R., & Zambo, D. (2007). Mathematics and the learning cycle: How the brain works as it learns mathematics. *Teaching Children Mathematics, 14*(5), 265-270.

Zull, J. E. (2002). *The art of changing the brain: Enriching teaching by exploring the biology of learning*. Sterling, VA: Stylus Publications.

Overall Appendix

Appendix A

Pre-Test

1. How is teaching math like teaching science? What is similar and what is different?

2. How would concrete tools/experiences play a role in a science lesson? Give examples.

3. How would concrete tools/experiences play a role in a math lesson? Give examples.

4. Name and describe a few teaching strategies or approaches used to teach science for meaningful understanding.

5. Name and describe a few teaching strategies or approaches used to teach math for meaningful experiences.

Appendix B

Post-Test

1. How is math like teaching science? What is similar and what is different?
2. How would concrete tools/experiences play a role in a science lesson? Give examples.
3. How would concrete tools/ experiences play a role in a math lesson? Give examples.
4. A. Name and describe a few teaching strategies pr approaches used to teach science for meaningful understanding.

   B. Name and describe a few teaching strategies or approaches to teach math for meaningful understanding.
5. A. Think back to a science lesson that you taught this summer and briefly describe it.

   B. How do you think it met effective practice approaches to teaching? Explain.
6. A. Think back to a math lesson that you taught this summer and briefly describe it.

   B. How do you think it met effective practice approaches to teaching? Explain.
7. How has the blog helped you in your development of…

   A. Ideas about teaching science?

   B. Ideas about teaching math?

   C. Similarities between the teaching of math and science?

Appendix C

Weekly Blogs

Weekly Blogs

Week 1: Why is following a Learning Cycle so important in teaching science? Won't more traditional approaches such as giving information first to students, such as in reading the textbook, completing worksheets, and writing notes/definitions work just as well? Why not? I am not convinced!

Week 2: We have learned about inquiry and the associated process skills for teaching science through 'doing science'. We have learned that the Learning Cycle for planning and teaching a series of lessons is 'best practice' to maximize student engagement and understanding of the science we are teaching - often called a "hands-on, minds-on" approach. So, how does the Science-Technology-Environment-Society piece fit into all of this? What really is it anyway? How does it work, and is it important in my science teaching? Please explain and help clear up my confusion.

Week 3: So, this week you had the chance to finally practice teach about either ecological or technological ideas to kids, and followed some portion of the Learning Cycle to do it! (whether an 'exploration' activity to first develop students' common understandings OR an 'elaboration' activity to get them to apply their previous learning to a new situation or use). Also, assessment was on everyone's mind. So, how did you assess your students' attitudes, understanding, or performance in your lesson this week? Do you feel your assessment strongly aligned with your learning objective(s)? Was it authentic enough? Why is assessment so important anyway? Share your thoughts about your thinking and how you are feeling about assessment.

Week 4: This week we have been doing many hands-on activities in our FOSS Earth Materials kit curriculum. All of the hands-on activities have been pretty fun, or at least interesting. Most of us really believe that ‘hands-on’ is the best way to go in teaching science, but is there more to it? What do you think? Are all hands-on activities equal? Is hands-on best no matter what you do, when you do it, or how you do it? Explain to me your thinking now about ‘hands-on’ activities in science to best help student learning. I know that you can help me understand this approach better and are pretty knowledgeable about how to do it best.

Week 5: Kids and stuff everywhere! Inventing and building and Newton’s Laws of Motion can certainly seem to be unruly in the classroom, but is this O.K.? Taking kids outdoors to learn about science in nature also has its own planning and managing hurdles, but is it worth it? Even in doing the state of Alabama’s science teaching in the classroom (AMSTI) with kits, there is a level of uncertainty and messiness with kids and materials ‘in motion’, but it seems to work. How are you now feeling about these issues? Where do you begin personally in your future classroom? What is your current thinking and your plan?

Week 6: Think about the Learning Cycle. Explain how the Learning Cycle pertains to the teaching and learning of mathematics. Support with examples. Then respond to two other people's responses.

Week 7: So far in class we have discussed inquiry in mathematics, assessing mathematical understanding, developing number sense, and participating in tasks to develop our own mathematical knowledge. Think about all we have talked about, experienced for ourselves, and experienced with students. Explain which part of the Learning Cycle you find to be the most important in developing a true understanding of mathematics and why. Support with examples of your own experiences or mathematics field experiences.

Week 8: In class we have been learning about how to assess and different types of assessment. Think about one of your math teaching experiences this semester. How did you determine student understanding of the topic? Be specific. Support with examples. Based on your assessment what judgments and decisions will you have to make about teaching/learning? Would you teach the lesson differently if you taught it again? Be specific. Support with examples.

Week 9: We have used concrete materials in class and with students in lab. I want you to think about the role that concrete experience plays in learning. Think of an instance in which concrete experiences played a role in your own learning of mathematics. Describe that learning experience. Describe how you have used concrete experience in one teaching lesson this term.

Week 10: Think about the two consecutive lessons you taught this week. What growth did you see in your students' understanding of the topic? What role did concrete experience play in your lessons? How did you promote inquiry?

Appendix D

Follow-up Discussion Questions

Pedagogical practices

1. In both science and math methods classes we focused on the Learning Cycle. What role did the Learning Cycle play in your lesson development and implementation?
2. What specific teaching practices were you working on improving through the teaching of this lesson?

Processes for meaningful learning

3. What role did inquiry play in the lesson? In what ways do you feel you promoted inquiry?
4. What connections between mathematics and science did you want students to make? How did you design the lesson to promote students making those connections between mathematics and science?

Tools for conceptual development

5. In what ways did you use tools for conceptual development?
6. Would you use the tools differently next time you teach the same lesson? If yes, explain how you would use the tools differently. If no, explain why you would keep the use of the tools the same.

Appendix E

Final Reflection

1. How is math like teaching science? What is similar and what is different?

2. How would concrete tools/experiences play a role in a science lesson? Give examples.

3. How would concrete tools/ experiences play a role in a math lesson? Give examples.

4. Name and describe a few teaching strategies or approaches used to teach science for meaningful understanding.

5. Name and describe a few teaching strategies or approaches to teach math for meaningful understanding.

6. A. Think back to a math lesson that you taught during student teaching and briefly describe it.

B. How do you think it met effective practice approaches to teaching? Explain.

Appendix F

Coding Guide

Coding Guide

Codes developed as the data was analyzed. Below are the major codes that developed. Codes that did not answer the research questions were not included.

Coding Family: Tools

Code	Description	Example
Procedures	Quotations in which tools are for procedures	"Solve problems to get answers"
Science book	Quotations in which tools are to enhance science textbook	"Tools allow students to see concepts read about in science book"
Real-World	Quotations in which tools are for real-world math	"Math is taught using tools such as time, money, cooking"
Hands-on	Quotations in which tools are for hands-on learning	"Hands-on-sees things first hand, understand why things happen in science"
Within Teaching Approach	Quotations in which tools are key in teaching approach	"use tools for students to see problem, students develop their own methods , students show how they got an answer

Coding Family: Processes

Code	Description	Example
Answers	Quotations in which processes are for answers	"Work together on a math problem to figure answer"
Communication	Quotations in which processes to foster communication	"Students discuss answer with peers"
Reasoning	Quotations in which reasoning was a focus	"Students explained why shapes were polygons"
Multiple processes	Quotations in which multiple processes work together	Explore-students work through problems and come up with solutions, have group discussion
Tools Build	Quotations in which tools were used to build processes	"Used tools for students to reason about measurement"

Coding Family: Pedagogical Approaches

Code	Description	Example
Games	Quotations in which the approach for math are games	“Math games allow for fun experience with math concepts”
Hands-on-structured	Quotations in which the approach is hands-on but structured	“Hands-on has to be structured and well planned”
Answers	Quotations in which the approach is to elicit right answers	“Asked questions for students to answer problems”
Reasoning then formula	Quotations in which the focus of teaching reasoning before giving formula	“Give experiences that give skill reason rather than giving a formula”
Common Approach	Quotations in which sees common approach for science and math	“Science and math both use group activities, hands on, and learning cycle”
Different Approaches	Quotations in which sees math and science as being taught in different ways	“Hands-on for science, Work problems in math”

Coding Family: Learning Cycle

Code	Description	Example
Steps	Quotations in which the learning cycle is described in prescribed steps	“follow each step”
Partial	Quotations in which only recognizes certain aspects of the learning cycle	“Engaged –talking about something they are interested in”
Complete	Quotations in which fully sees all parts of the learning cycle	“Important to consider all parts of the learning cycle”

Appendix G

Sample Coding Level 1 Phase I

Sample Coding Level I Phase I

T	Sci-Hands-on allows for trial and error (pre) Sci-Remember info through experience (pre) See math applied (pre) Math-Learn skills-Pre Math-More engaging Pre Ex: money, time , cooking Pre Stu made art from recyclable materials (b3) Allows stu to interact with learning (b4) Hands-on must be clearly explained and applied Concrete experiences with money –making change (b9) Sci- concrete experiences-help stu observe and come to realizations (post) Stu make discoveries, construct knowledge Challenge stu thinking Math- Post Find meaning and reasoning Application for math skills (post)-saw importance of concrete experiences for both subjects
PA	Experiments and hands-on for sci (pre) Sci-info for key facts Math-games, fun experiences (pre) Flash cards –remember key facts Checked stu progress with assessment (b3) Hands-on has to be structured and well planned (b4) Concerned with est authority and management (b5) (b8) Asked questions for stu to -Concerned with stu getting the right answer (b8) Sci –Post Using 5 E's of LC Stu experiment-discover truths rather than lecture Stu observed in lesson Math (post) Give experiences that give skill reason rather than giving a formula Stu folded and cut shapes, discussed
P	Realistic application b1 Stu see purpose of sci and applications-connections b2 Use natural curiosity to solve problems b6 Explore phase stu expand their knowledge-reasoing-b7 Discussion to see if stu get right answer b8 Felt like she needed to guide ps more b8 Math-money-real life application b10
CA	Can approach both with natural curiosity (b6) Both requires hands-on interactive learning (post)

LC	Levels the playing field (b1) Students given reason why Gives stu realistic application Helps stu see many purposes of scie (b2) Stu more interested in learning Can be applied to math (b6)-engage, activate PK Confidence booster Use engage time to level the playing field (b6) Without enough exploration-stu will have difficulty grasping concepts (b7) If not properly engaged stu will get lost in the lesson Have to activate PK for stu to understand concepts

Appendix H

Sample Coding Level 2 Phase I

CT	Moved from seeing tools in science as teacher controlled experiments for students to see to students understanding the phenomena for themselves Moved from seeing money as being a concrete tool to the use tools for students to see problem, students developing their own methods, and students showing how they got an answer.
PA	Initially see science as teacher controlled experiments. She also considers traditional methods to ok with the LC at the beginning of methods class. After working in FEP believes science can be other than hand-on with interactive worksheets and journals. By the end realized the lesson she taught was effective because of her use of the LC. Wants math to relate to the students lives. Initially she sees math as being group work and hands-on. Her FEP experiences show her that students think differently about math and still come up with the answers. Her conceptions of inquiry in math are not real inquiry though. Proud of correct answers from students. Wants students to be able to show her how they came up with their answer. Fun
P	Science journals Encouraging discourse Asking challenging questions
LC	Traditional approach criticism Wants to explain topics better Realized students could develop their own methods that would work Thinks the LC is effective because it helps the students learn the material in depth.

Appendix I

Sample Coding Level 3 Phase I

PA	Likes the idea of inquiry and hands-on, still tries to figure in traditional, wants stu to get answers by themselves (1, 7, 16, 17, 20) Sci-holding onto traditional, math-hands-on (2) Concerned with facts for math and sci, hands-on can follow-(3) Started with traditional views about sci and math. FEP influenced and changed ideas to more hands-on for sci and math (4, 6,10) Initially believed hands-on for sci and math. FEP reinforced (5, 8, 9, 11, 13, 14, 15, 21, 22) Initially believed hands-on for science and a more traditional approach for math –in the end thought what she was teaching in math was "inquiry" but still more along traditional (12) Sees the importance of hands-on but in the context of fun or a reward when students have been good and earned it (18) Science went from students to hands-on to students understanding from hands-on as well as making connections and relating science to real life situations. For math went from idea of students working in groups by skill level to students using concrete experiences to understand (19)

Appendix J

Sample Coding Phase II Jane

Sample Coding Phase II Jane

	Initial codes	Secondary codes
T	Demonstrates how to measure to nearest ½ and ¼ inch 4-14, O	Tools for measurement-procedural focus
	Showing them how to measure different items on projector	
	Students given rulers to measure books, noses 4-14, O	
	Wanted them to be able to move around 4-14 FI	
	Would have had more items 4-14, FI	
	Wanted them to go around the room and measure-didn’t get to that 4-14-FI	Didn’t use tools often as wanted
	Labels number line with fractional increments 4-15 O	
	Students measuring items	Tools for measurement-procedural focus
	Show circle graph from Illuminations 4-16 O	
	Has students use tiles to make a bar graph of data collected 4-16 O and 4-16 FI	Tools for representations of information
	Used sticky notes earlier in the day to collect data 4-16 FI	Tools for active involvement, engagement
	Using the computer to make to circle graphs 4-16 FI	Tools for representations of information
	Labels coordinate grid on board 4-21 O	
	Uses coordinate grid on doc cam with boat cutout 4-21 O same as LP	Tools to reason and make connections between representations
	Uses large floor grid 4-21 O	
	Students move on coordinates on floor grid 4-21 O	
	Fraction circle magnets 4-22 O	Tools for active involvement, engagement
	Wanted students to have their own but that wasn’t possible 4-22 FI	
	Used to engage and think about fractional parts	Tools for engagement
	Used whole for them to show me what it means	Tools for representations
	Uses animals to show how many out of	Tools to make connections to concept
	Uses pattern blocks for students to make cookies	
		Tools for student to demonstrate knowledge
	Fraction circles students put together 4-23 O	
	Students make equivalent fractions with pieces 4-23 O	
	Worried about use of fraction circles 4-23 FI	Trying to promote inquiry with students finding equal pieces
	Ended up being more teacher directed 4-23 O	
	Would add a recording chart so students could refer to what color means what fraction 4-23 FI	
	Instead of standard algorithms students should be able to solve different ways FR	